MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS AND TELECOMMUNICATIONS DEPARTMENT OF AVIONICS

APPROVED
Head of department
__________S. Pavlova
(signature)
‘___’__________2021

GRADUATION WORK

(EXPLANATORY NOTES)
GRADUATE OF AN EDUCATIONAL DEGREE «BACHELOR»

Theme: «Laboratory testing of digital aerial camera»

Done by:____D. Bielinskyi
(signature)

Supervisor:____L. Sitnyanskyh
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Standard controller:___________________________________ V. Levkivskyi
(signature)

Kyiv 2021

NATIONAL AVIATION UNIVERSITY

Faculty of Air Navigation, Electronics and Telecommunications

Department of avionics

Specialty 173 ‘Avionics’

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TASKS

Bielinskyi Denys Oleksandrovych

1. **Theme of graduation work:** ‘Laboratory testing of digital aerial camera’, approved by order №459/ст of the Rector of the National Aviation University of 1 May 2021.
2. **Term of performance of work:** from 01.05.2021 to 04.06.2021.
3. **Input data of graduation work:** Creation of a manual for online lessons. Choosing the right hardware and software, setting up equipment and getting started step by step.
4. **Content of explanatory notes:** Analysis of flight and tactical characteristics of air surveillance aircraft and tactical and technical characteristics of digital aerial cameras. Research and analysis of the hardware and software complex for digital aerophotography. Methods for determining the efficiency of a digital aerial camera. Laboratory testing of a digital camera.
5. **The list of mandatory graphic material:** figures, charts, graphs.

6. Planned schedule

№	Task	Duration	Signature of supervisor
1.	Varification and validation of graduation work theme	18.02-26.02	
2.	Carry out a literature review	01.05-20.05	
3.	Develop the first chapter of diploma	21.05-23.05	
4.	Develop the second chapter of diploma	24.05-02.06	
5.	Develop the third chapter of diploma	02.06-05.06	
6.	Develop the fourth chapter of diploma	05.06-08.06	
7.	Tested for anti-plagiarism and obtaining a review of the diploma	09.06	
8.	Documents preparation for passing the graduation work	09.06-15.06	

7. Date of assignment: ‘____’___________ 2021

Supervisor ________________ __________________________
(signature) (surname, name)

The task took to perform ________________ __________________________
(signature) (surname, name)

ABSTRACT

Explanatory note to the graduation work ‘Laboratory testing of digital aerial camera’:

64 pages, 30 figures, 9 tables, 7 sources.

DIGITAL AERIAL CAMERA, LABORATORY TESTING, FREQUENCY-CONTRAST CHRACTERISTIC, RESOLUTION, MATRIX.

Object of investigation – digital aerial camera.

The purpose of the graduation work: to investigate the testing of a digital aerial camera in the laboratory, to optimize and improve the testing process.

Method of investigation: testing a digital aerial camera by determining its resolution (using an optical bench and a bar pattern) and frequency-contrast characteristics (using a test pattern and the RightMark Video Analyzer program).

Materials of graduation work are recommended for further research, educational process and practical activities of specialists.

CONTENTS

LIST OF ABBREVIATIONS

APC – aerial photo camera

OS – ‘Open Sky’

FTC – flight-technical characteristics

CCD – charge-coupled device

FCC – frequency-contrast characteristic

RMVA – RightMark Video Analyzer

RF – red filter

OF – orange filter

YF – yellow filter

W/ F – without filters

INTRODUCTION

Aerial photography during patrols is carried out with the use of surveillance aircraft equipped with topographic or reconnaissance aerial cameras. Most observation flights are performed using topographic aerial cameras, while reconnaissance aerial cameras are used to obtain more complete information from significant altitudes of observation flights.

Of course, you can use unmanned aerial vehicles for aerial photography, but they have a number of disadvantages, such as: range restrictions. While the aerial camera installed on the plane can shoot at much higher altitudes, which allows you to cover more terrain and with more time, which allows you to collect more data.

Today, digital aerial cameras are increasingly being replaced by digital ones. However, the invention of the matrix, though ingenious, needs further improvement. Therefore, to make sure that the final image is of good quality, it is necessary to properly test the camera before using it.

The choice of this topic is that there is a need to find a way to perform tasks related to aerial reconnaissance and ground surveying to build maps faster and at a lower cost, improving the testing of aerial cameras.

CHAPTER 1
ANALYSIS OF FLIGHT AND TACTICAL CHARACTERISTICS OF AIR SURVEILLANCE AIRCRAFT AND TACTICAL AND TECHNICAL CHARACTERISTICS OF DIGITAL AERIAL CAMERAS

1.1. Analysis of the technical characteristics of surveillance aircraft

The issue of the level of security of society and the state has always been central to public policy. It is especially important today. This applies not only to the control of the borders of our state, but also to natural phenomena and catastrophes, the consequences of which can lead to the death of people. Timely detection of dangerous situations is solved by observation and reconnaissance. After all, for the successful conduct of hostilities and defense, the main efforts are focused on monitoring the actions of the enemy, collecting and processing data on military facilities in its territories. And to save citizens from natural disasters and their consequences, it is necessary to have information about the epicenters of events in order to provide timely assistance and predict the further development of the situation.

Requirements for surveillance aircraft

According to the Open Skies Treaty of March 2, 2000, the maximum flight range for Ukraine over the territory of the countries that have ratified the Treaty, which starts at the Boryspil Open Skies airfield, is 2100 km. (Table 1.1)

Table 1.1

Requirements for surveillance aircraft

maximum flight altitude H_{max} with 8 observers, m	11500
Max. flight range at an altitude of H = 1000m. with 8 observers, km	3500

The cabin of the surveillance aircraft shall have 3 workstations for surveillance equipment operators and 8 additional workplaces for inspectors of participating countries and persons accompanying them.

The panoramic aerial photo camera (APC) must provide a resolution of 0.3 m in the area, which is measured as the contrast K = 0.4 when shooting from a height of 8000 m. The field of view of the panoramic AFA is not less than 93 degrees.

Personnel APC must have equipment that would provide a resolution of 0.3 m, with a contrast of K = 0.4, shooting from a height of 1000 to 2600 m. The total angle of view of personnel APC is not less than 70 degrees.

Flight data annotation equipment shall provide registration during the observation flight at the beginning and end of each roll of negative and at the beginning of each second storage medium the following:

- number of the observation flight;
- date of observation flight;
- scheme of finding surveillance equipment;
- focal length.

<u>Analysis of surveillance aircraft and their FTC</u>

An-74MP

The An-74MP [1] patrol aircraft was created on the basis of the An-74 aircraft. It ensures the performance of the maritime patrol service and the detection of intruders in the area adjacent to the coast during the day and at night in simple and difficult weather conditions.

Additionally, the equipment of the cargo compartment (7 m long) allows to:

- airborne landing of 22 paratroopers with personal weapons and equipment;
- transportation of 44 soldiers with personal weapons and equipment;
- transportation of 16 wounded on stretchers accompanied by a medical worker;
- transportation of ammunition, materiel and technical property with a total weight of up to 10,000 kg.

To solve patrolling tasks, the composition of the crew was supplemented by a navigator and a radio operator, for whom separate workplaces were equipped. Both workplaces are located near the blisters for visual inspection of the land or sea surface.

The aircraft is equipped with:

- an aiming and navigation and aerobatic complex providing automatic navigation at all stages of flight, taking the aircraft to a given point, instrumental search, determining the coordinates of surface vessels, their speeds and movement courses;
- stationary photographic equipment providing aerial photography of targets;
- in the daytime, planned and prospective, with a location referenced to geographic coordinates;
- scheduled night time using lighting bombs;
- radio communication equipment providing communication with ground points and between aircraft, radio guidance to detected ships of a border or other ship in the MV, UHF, SV and HF bands;
- weapons, ensuring the creation of obstacles to the movement of intruder ships, opening fire from a 23-mm GSh-23L cannon, launching unguided missiles from UB-32M blocks and dropping 100 kg bombs;
- a television system for viewing the underlying surface, ensuring operation in night and day conditions.

The cargo compartment is pressurized, equipped with an air conditioning system, which creates comfortable conditions at altitudes up to 10,000 m, and can be used to transport people on board and central removable seats, including seats on the ramp. The side seats are folding and may not be removed when using the aircraft in the cargo version.

A large cargo hatch is located in the tail section of the cockpit. The cargo hatch opening is closed by a ramp, which can either descend to the ground and serve as a ladder for loading wheeled vehicles, or move under the fuselage, completely freeing the hatch opening for loading an aircraft from the car body or for airborne paratroopers.

To carry out loading and unloading operations, there is a loading device with a lifting capacity of 2500 kg on the ceiling of the cargo compartment, and the installation of removable roller table equipment is provided on the floor.

FTC of An-74MP is shown in Table 1.2.

Fig. 1.1 The aircraft An-74MP

Table 1.2

FTC of An-74MP

Wingspan, m	31,89
Length of the aircraft, m	28,07
The height of the aircraft, m	8,65
Wings area, sq.m.	98,62
Weight, kg - empty plane - maximum	 19050 32000
Internal fuel, kg	13210

Engine type	2 TRD Progress (Lotarev) D-36 series 4A
Traction, kN	2 x 63.80
Maximum speed, km/h	725
Cruising speed, km/h	600 - 680
Payload	650 kg of cargo when patrolling
Duration of patrol, h	8-9
Practical ceiling, m	10600
Crew, pers.	2+4

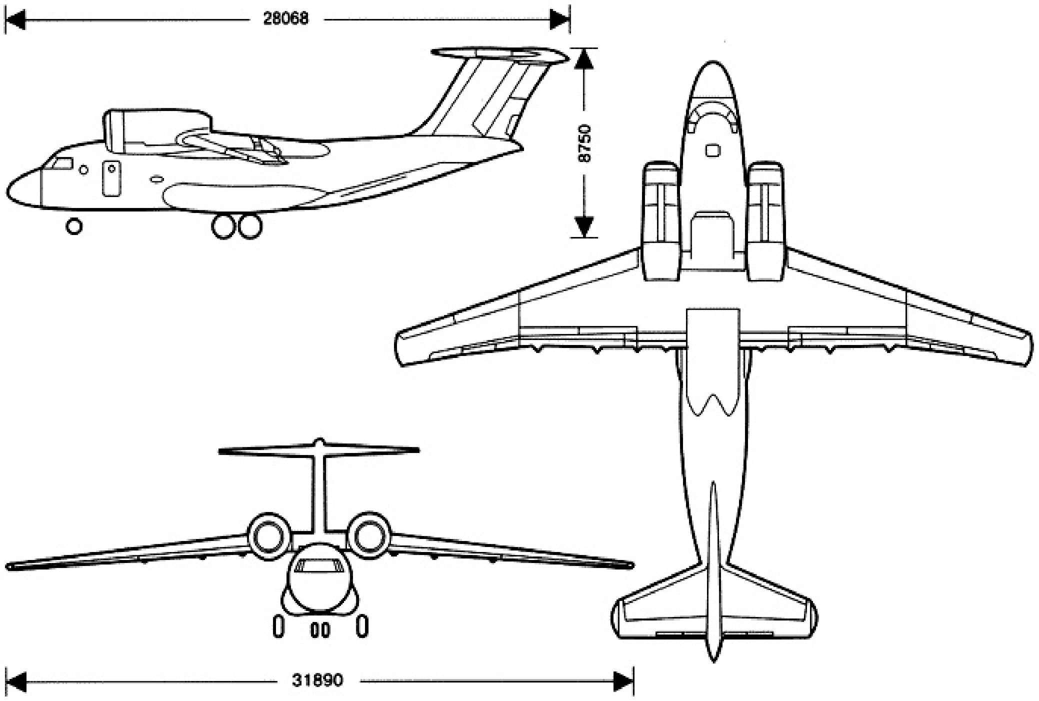

Fig. 1.2 Overall dimensions of AN-74MP

An-148MP

SE "Antonov" has developed the An-148MP sea patrol aircraft. An-148MP was designed to control the sea space, monitor environmental pollution and radiation. To accomplish the assigned tasks, the aircraft is equipped with such equipment as radar and optical-electric search, which ensures the search for targets on the water, as well as blisters on both sides of the fuselage, which provide visual search for the target. The aircraft can be armed with guided and unguided air-to-ground missiles.

An-148MP during special operations can drop soldiers or help in a disaster area. This operation can take place through a hatch under the wing or through the rear cargo door of the cargo compartment. To control the contamination zone, the aircraft is equipped with SLAR, MWR, IR \ UV, LFS systems. Thanks to its spacious cargo compartment, the An-148MP can carry, if necessary, both personnel and military equipment. The maximum flight duration is 10 hours. Due to its design, the aircraft can be operated on unpaved airfields. In addition, the aircraft can operate both in cold climates and in very hot regions of our planet.

FTC of An-148MP is shown in Table 1.3.

Table 1.3

FTC of An-148MP

Wingspan, m	28,91
Length of the aircraft, m	29,13
The height of the aircraft, m	8,19
Wings area, sq.m.	87,32
Internal fuel, kg	12050
Engine type	2 TRDD D-436-148
Cruising speed, km/h	800-870
Practical ceiling, m	12200
Crew, pers.	2+3

Fig. 1.3 The aircraft An-148MP

Tu-214OS

Tu-214OS [2] (codenamed ‘Open Sky’) is an aircraft designed for aerial surveillance, developed at JSC Tupolev on the basis of Tu-214 passenger aircraft. The aircraft was created specifically for flights under the Treaty on the open skies over the territory of the countries participating in the treaty and to replace the Tu-154M LK-1 and An-30B aircraft.

Tu-214OS is equipped with an on-board aviation surveillance kit, which was developed by JSC "Concern of Radio Engineering" Vega ". It includes panoramic and personnel aerial photographic equipment, infrared and television cameras, radar for side viewing. The resolution limit for infrared cameras is 50 centimeters, for digital cameras - 30 centimeters.

The on-board aviation surveillance kit is designed to obtain a record of the received materials, images of the terrain, document surveillance equipment and other incoming information, control the means of formation and observation of navigation data for surveillance equipment.

The aero photo complex is represented by film and digital cameras, which are located on the lower deck in the forward fuselage. The side-looking radar is also located at the front of the fuselage. The radar range reaches from 4.7 to 25 kilometers, and the coverage area reaches 50 kilometers. The infrared spectrum observation equipment is located in the center section. The viewing angle range of infrared equipment is 130 degrees, the track width on the ground is 4.6 * flight altitude indicated by the radio altimeter. The television surveillance complex includes three cameras: a wide-angle central KTSh-5 and two side KTBO-6. The viewing angle of the KTSh-5 is 148 degrees, the width of the terrain tracking is 6.6 * flight height indicated by the radio altimeter. The viewing angle of KTBO-6 is 8.5 degrees in a narrow focus, and 20.1 degrees in a wide focus with a range of viewing angles of 60 degrees.

The aircraft is equipped with an onboard computer complex. It is intended to monitor the operation and control of surveillance equipment, in addition, to display information in real time from various surveillance facilities, as well as to record it. It includes five workstations (automated workstations), which are integrated into a local network: workstation for the radar operator, workstation for the aerial photo complex operator, workstation for the TV equipment operator, workstation for the IR equipment operator and the workstation for the flight senior representative.

FTC of Tu-214OS is shown in Table 1.4.

Fig. 1.4 The aircraft Tu-214OS

Table 1.4

FTC of Tu-214OS

Wingspan, m	42,00
Length of the aircraft, m	46,20
The height of the aircraft, m	13,90
Wings area, sq.m.	182,40
Weight, kg - empty plane - maximum	 59000 110750
Engine type	2 x TVRD PS-90A
Traction, kgf	2 x 16000
Cruising speed, km/h	850
Practical ceiling, m	12000
Practical range, km	6500
Crew, pers.	2+3

1.2. TTC analysis of digital aerial cameras

Aerial photography is the best way to demonstrate the area from a bird's eye view. Thanks to aerial photography, many opportunities open up:

- Determining the places and boundaries of catastrophic disasters;
- Controlling the development of emergencies;
- Identification of methods and routes of evacuation;
- Monitoring and control of situations at the state borders (sea, land);
- Conducting military intelligence.

Medium format digital aerial camera AIC Modular LS 22MPix

- 22 megapixel sensor resolution;
- Low price when buying a used camera;
- Pre-sale preparation with replacement of all wearing parts.

Fig.1.5 Digital aerial camera AIC Modular LS 22MPix

The AIC Modular LS 22MPix [3] industrial digital aerial camera combines the advantages of digital technology, the reliability of industrial equipment and a reasonable price.

Digital technology of receiving and processing of data allows to accelerate as much as possible process of processing of results of shooting, and also to exclude stages at which deterioration of quality of material is possible. Primarily processed images are suitable for use in all modern photogrammetric software products.

The wide dynamic range of pictures allows to make shooting both in cloudy weather, and at the bright sun. It is also possible to correct pictures taken with incorrect shooting parameters (operator error).

Digital aerial camera TwinMapper

The TwinMapper [3] digital topographic aerial camera is a general-purpose digital aerial camera used as a means of topographic mapping of terrain, performing engineering surveys, as well as for solving special tasks involving the collection of geospatial data by aerial photography methods. ...

TwinMapper is a full-featured metric frame-type aerial camera that allows the use of GPS / IMU means for automatic determination of external orientation elements, gyro platform and flight management system.

The set of standard software, along with navigation support, planning an aerial survey project and processing GPS / IMU data, includes specialized programs that provide the formation of a standard digital aerial photograph of a rectangular shape with well-defined metrological properties.

Photogrammetric processing of TwinMapper aerial photography data is carried out using standard tools, for example, using Erdas Imagine, Socket Set, Photomod, etc.

Fig.1.6 TwinMapper installed on a GSM-3000 gyro platform

Digital aerial cameras from Microsoft Vexcel

Digital aerial cameras of the frame type of the Vexcel UltraCam class by Microsoft Vexcel [3] are designed for aerial photography in order to solve a wide range of applied and topographic and geodetic problems, including for:

- creating and updating topographic maps and plans up to a scale of 1: 500
- creation of DEM, DTM and large-scale orthophotomaps

- creation of high-precision 3-dimensional digital models and maps of cities, etc.

Aerial cameras of this class allow you to simultaneously obtain panchromatic, RGB and NIR images, use the method of synthesized frame formation, and are easily integrated with all standard gyro platforms, GPS / IMU systems, laser scanners, hyperspectral sensors, etc.

Fig.1.7 Digital camera UltraCamX

The characteristics of cameras of the UltraCamX family are shown in Table 1.5.

Table 1.5

TTC of cameras of the UltraCamX

Characteristics	UltraCamX	UltraCamXp
Full frame size	136 megapixels	196 megapixels
CCD matrix element size	7.2 μm	6 μm
Has the possibility of unlimited accumulation of images on board the aircraft (without landing) - thanks to removable	up to 3900 uncompressed frames in each removable memory block	up to 6000 uncompressed frames in each removable memory block

memory units		

Fig.1.8 Digital camera UltraCamL

The characteristics of cameras of the UltraCamL family are shown in table 1.6.

Table 1.6

TTC of cameras of the UltraCamL

Characteristics	UltraCamL	UltraCamLp
Full frame size	64 megapixels	92 megapixels
CCD matrix element size	7.2 µm	6 µm
Has the possibility of unlimited accumulation of images on board the aircraft (without landing) - thanks to removable memory units	up to 3900 uncompressed frames in each removable memory block	not less than 2500 uncompressed frames in each removable memory block

CHAPTER 2
RESEARCH AND ANALYSIS OF THE HARDWARE AND SOFTWARE COMPLEX FOR DIGITAL AEROPHOTOGRAPHY

The history of the invention of the camera and photography dates back to the 17th century. At that time, astronomer Johann Kepler was able to apply the laws of refraction and project images on a flat surface. However, it was not until 1820 that Joseph Nicéphore Niepce managed to not only design but also capture such an image. Niepce used asphalt varnish to fix the image.

The first attempt at aerial photography was made in 1855 by the French photographer Nadar. To do this, he used a conventional camera at the time, the purpose of which was portrait photography. In 1884, the Frenchman Tiboulier created the first specialized aerial camera for several plates. However, the greatest development of aerial cameras began after the creation of the first aircraft. which were more suitable for reconnaissance, compared to balloons.

In order to be able to aerial photography from a single aircraft, most processes must be automated. This aerial camera was first created by Russian scientist Potte in 1913. Instead of photographic plates, coil photographic film was used in it. At that time it was the world's best aerial camera design. Such cameras were used in the USSR for reconnaissance and topography until the late 1920s.

However, in 1918, Kodak began production of the world's first fully automated K-1 aerial camera. In the USSR, the first automated aerial camera "APC-13" was created in 1934.

All cameras at the turn of the XX and XXI centuries are gaining special development.

This is when digital aerial cameras appear. Such chambers use CCD arrays instead of film.

Such cameras are becoming increasingly popular compared to film cameras, because they are much easier to use and maintain.

2.1. Analysis of the characteristics of aircraft surveillance equipment

Types and designs of modern aerial camera are diverse, but they are basically one schematic.

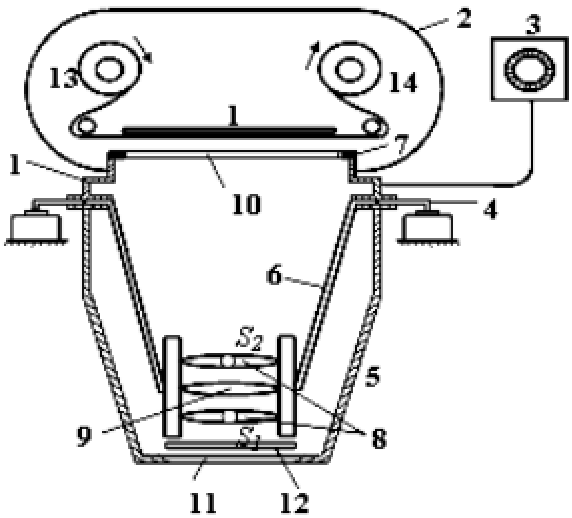

Fig. 2.1 Scheme of aerial camera

The main parts of each aerial camera are: body - 1, cone with optics - 6, cassette - 2, control device - 3 and aerial installation - 5.

Today, in contrast to film aerial cameras, digital aerial cameras have a CCD array instead of a cassette, on which an image is projected, which is later stored on a memory card. In this case, digital aerial cameras have a significant number of advantages, one of the most important of which is that the Germans from digital aerial camera do not need to show. Such images are ready for viewing on any digital device with a display.

Today, the digital aerial camera is a complex electronic optical-mechanical device with the most automated process of work performed on the electrodes of the station control.

Compared to a film aerial camera, digital has a more complex structural and functional scheme.

Fig.2.2 Structure of digital aerial camera

In Fig. 2.2 shows a digital aerial camera and its main structural components: 1- heating and cooling system; 2 - electronics unit; 3 - inertial measuring device; 4 - unit with CCD matrix, filter and beam separator; 5 - telecentric lens; 6 - video camera; 7 - external protective filter; 8 - housing temperature compensation for lenses; 9 - control module.

The heating and cooling system is a system that helps to facilitate the operation of the aerial camera and its units at different temperatures. Thus extend its service life.

The electronics unit is a unit in which the chips are placed, which are the "brain" of the aerial camera.

An inertial measuring device is a special unit that, when shooting, records to a file data on the placement of digital aerial camera in space, as well as time and speed.

Digital photography uses several types of matrices (sensors), which can be classified by the method:

- charge reading: CCD, i.e. CCD and CMOS, i.e. K-MON;
- color separation: matrices with Bayer filter and matrices without Bayer filter
- Foveon X3 matrices.

This aerial camera uses a CCD array and it is perhaps the most important component of an aerial camera. Thanks to the invention of such an element as the CCD matrix, today we have the opportunity to take digital pictures. The matrix is the sensor of the camera, thanks to it the light is converted into an electric charge and we get a digital image. This transformation is due to the fact that the matrix is an analog device. When light hits the pixels of the matrix, a small charge is created on them, which is removed and converted into a colored peak of the digital picture. The matrix must have a large resolution and resolution for high image quality.

The telecentric lens is a unique device that helps to align the image that was taken with the lens and that is distorted through the lens. This lens aligns the image rays parallel to the optical axis.

Video recording is an additional option, but it is not used on all digital aerial cameras, but if necessary, allows you to take video with the same aerial camera.

The external protective filter is part of the lens, but it does not affect the image quality. These lenses are used to protect the camera lens from mechanical damage, thus extending the life of the camera itself. Moreover, in terms of the cost of the lens of an aerial camera, the lens costs much less, which clearly justifies its usefulness.

The temperature compensation housing is designed to protect the lens of the aerial camera lens. It's no secret that making lenses is a very expensive process. Of the batch of manufactured lenses, perhaps one will be successful. Therefore, to protect the lenses from temperature changes, they are placed in the housing of temperature compensation.

The control module is an executive body through which the camera is controlled. That is, when setting the settings from the command device, the control module drives them.

2.1.1. Analysis of the image forming system with CCD matrix

The structure of the matrix consists of a two-dimensional matrix of "cells" that are sensitive to light. In this case, each "cell" corresponds to an element of the image - a pixel. When we talk about extensions, we mean the product of pixels in height and length (for example, 4000x3000, etc.). Accordingly, the more pixels, the more detailed and sharp the image. Therefore, manufacturers provide the ability to specify the size of the image when shooting.

When we talk about the sensitivity of the matrix, we mean the ratio of the output voltage to the amount of light that hits the matrix per second. The sensitivity of the matrix is not constant in the spectral range. It depends on the wavelength of the radiation.

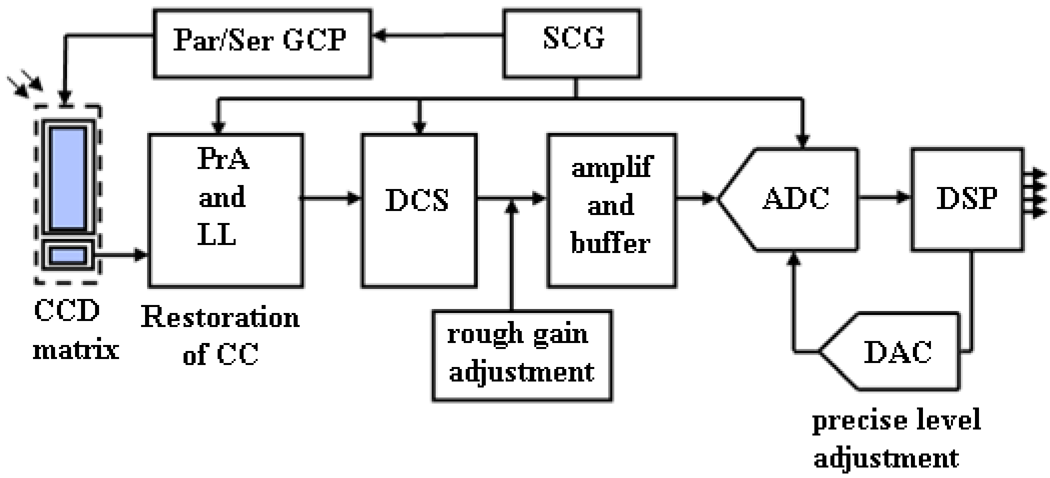

Fig.2.3 Image forming system with CCD matrix: a typical functional diagram

CCD matrix – matrix with a *charge-coupled device*; Par/Ser GCP - generator of clock pulses of parallel and serial register; SCG - setting clock generator; CC - constant component; PrA and LL - preamplifier and level lock; DCS - double correlated sample; amplif and buffer – amplifier and buffer; ADC – analog-to-digital converter; DSP - digital signal processor; DAC – digital-to-analog converter.

The CCD output signal is a stream of pixel charge packets that are converted to step voltage levels of direct current. This output signal also contains a bias voltage that reaches several volts. Later, the signal is passed through a capacitor to separate the DC voltage before entering the pre-amplifier. To maintain the desired relationship between the charge of the pixel and the reference level, in the first stage of processing usually using a latch or a circuit of recovery of the constant component. The next stage is used as a noise "suppression" circuit, which is designed to process signals from CCD matrix.

The next amplification stage may be an amplifier with automatic gain control (AGC) or a stage with a constant gain and offset adjustment. Before entering the ADC, the signal usually passes through a special buffer or driver circuit optimized for the selected type of converter. Further stabilization of the reference level can be achieved due to the presence of a DAC in the digital control unit.

The mathematical model of CCD matrix establishes a quantitative relationship between the internal parameters of the matrix, the input optical signal and the input electrical signal. This takes into account the factors of reducing the modulation factor at the input of the matrix compared to the input.

The spectral factor is the discrepancy between the spectral characteristics of the source, receiver and eye.

$$U_{min1} = (E_{min}*S_e*K_{пр}*K_{oe})/(K_{пе}*K_{op}); \quad (2.1)$$

$$U_{max1} = (E_{max}*S_e*K_{пр}*K_{oe})/(K_{пе}*K_{op}), \quad (2.2)$$

where S_e is integral reference sensitivity; $K_{пе}$ is the coefficient of use of the receiver of the reference source; $K_{пр}$ is the coefficient of use of the receiver of the working source; K_{oe} is the coefficient of eye use of the reference source; K_p is the coefficient of use of the eye of the working source.

The geometric factor is that the elements of the matrix have finite values. They cannot detect fluctuations in the input lighting at high spatial frequencies. If several strokes fall on one element, the signals from all strokes are integrated and the resulting signal will correspond to the average illuminance of the element.

$$T_г = \sin(\pi*V_m*A_в)/(\pi*V_m*A_в), \quad (2.3)$$

where $T_г$ is the geometric factor; V_m is the spatial frequency.

If the measure is located across the photo area:

$$U_{min2} = (U_{max1}*(1-T_г)+U_{min1}(1+T_г))/2; \quad (2.4)$$

$$U_{max2} = (U_{max1}*(1+T_г)+U_{min1}(1-T_г))/2. \quad (2.5)$$

Thermogeneration leads to the formation of a dark signal matrix at the output. If you close the camera lens with the black cover, it will still be possible to detect a dark noise signal at the camera output.

$$N_{tt} = (J_t*T_н*A_в*A_г*10^{-8})/Q_{ел}, \quad (2.6)$$

where N_{tt} is the number of dark; J_t is the dark current density (10); $T_н$ - accumulation time; $Q_{ел}$ - electron charge (1.6 * 10-18K); $U_t = N_{tt} * K$, where U_t is the dark voltage at room temperature; K is the conversion factor of voltage charges. Then:

$$U_{min3} = U_{min2} + U_t; \quad (2.7)$$

$$U_{max3} = U_{max2} + U_t; \quad (2.8)$$

The diffusion factor is that part of the charges diffuses, i.e. disappears from one packet and is added to another or recombined.

$$T_n = \exp(-N_n*e*(1-\cos(2*K_1))) , \quad (2.9)$$

where T_n is the diffusion factor; $N_n = 1.5 * M_в * N_ф$; $N_ф$ - number of phases; $K_1 = \pi * N_n * A_в$; e is transfer efficiency;

$$U_{min4} = (U_{max3}*(1-T_n)+U_{min3}(1+T_n))/2; \quad (2.10)$$

$$U_{max4} = (U_{max3}*(1+T_n)+U_{min3}(1-T_n))/2. \quad (2.11)$$

2.2. Analysis of components of modern digital aerial photography systems.

The process of obtaining aerial photographs is complex and requires many processes. In order to get quality and reliable material in the end result of shooting, it is necessary at least:

- Determine the purpose of shooting;
- Build and set the route in the software of the aerial camera;
- Adjust all the necessary camera settings for shooting;
- Conduct a survey and follow its progress;
- If necessary, convert files;
- Process the collected material;
- If necessary, create a three-dimensional module;
- Creating a project report.

An aerial camera alone will not be enough to perform all these minimal tasks. Therefore, together with the camera use certain components, such as:

- scanning module;
- flight control system;
- control computer;
- stabilizing platform;
- GPS / IMU Applanix POS AV.

2.2.1. ALTM Gemini 167 complex

Optech's ALTM Gemini 167 is one of the most reliable systems for data collection during aerial photography and digital terrain modeling. This system creates a digital terrain model with an accuracy of 5-10 cm.

The aerial camera of this complex differs from the previously presented in that in the course of its work it not only takes pictures, but also scans the surface with the help of optical phenomena of light reflection and scattering.

Fig. 2.4 ALTM Gemini 167 complex

This complex consists of:

• Camera module;

• Computer with software from the manufacturer;

• GPS module;

• Insulating platform.

Camera module

The camera module is essentially a scanning module, through which data collection takes place. The scanning module is an aerial camera, but works on the principle of "leader". Although this camera is called a "laser", it is not. The camera works on the basis of the analysis of light reflection and its scattering in transparent and translucent environments. The camera works at an altitude of up to 4000 meters.

During its operation, the camera does not transmit an image, but only a set of data in the form of code. To decrypt this code, you need a computer with software that decrypts the data from the camera and creates the terrain model itself. In this case, the data coming from the camera allows you to create images in a 12-bit dynamic range.

Computer with software from the manufacturer

Not all manufacturers of aerial photography systems provide their customers with software for complete data processing. Often these are separate programs, how to purchase them separately. However, Optech has provided full-fledged software for processing data from the aerial photography system. The computer is powered by 28 V DC. The computer also acts as a memory card because it records the collected data. There is also a connector for installing a flash drive and transferring data.

A tablet is attached to the computer, which is used to adjust the aerial camera before and during shooting.

GPS module

This module contains data on many satellite stations. It allows to link the collected data to the terrain during the survey.

2.2.2. Complex 3-DAS-1

Fig. 2.5 The composition of the aerial photo system 3-DAS-1

Scanning module

The scanning module of the aerial photo system consists of three independent channels, each of which has a color linear CCD sensor with 8000 pixels.

At the same time, each lens has a different angle of inclination in the direction of movement of the aircraft and allows a more thorough scan of the area, while capturing the maximum area.

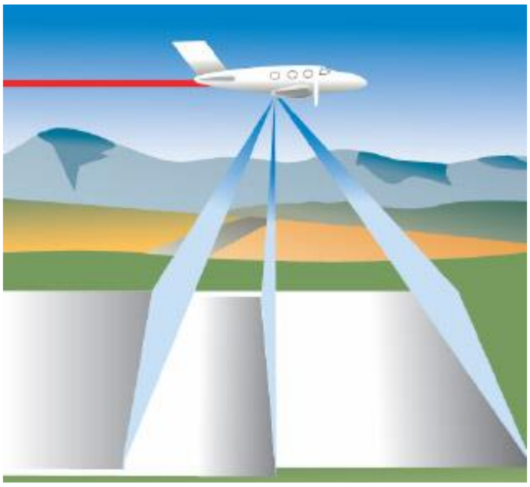

Fig. 2.6 Operation of the scanning module 3-DAS-1

The optical axis of the nadir channel is located vertically, providing an image close to the actual orthophoto. The other two channels (front and rear) have angles of 16° and 26°, due to which the system provides triple stereoscopic coverage.

All channels provide radiometric resolution 42bit (3x14). The scanning frequency is 250-750 lines/s.

Flight control system

It provides flight planning, routing, as well as navigation and trajectory control (flight management) during the flight. During the flight, it displays data on the current location and course, as well as deviations from the trajectory of the route. It allows to shoot with a deviation of the position of the routes within 20 m.

It includes a tablet computer and DIGITALS-FMS software to monitor the current position according to GPS data.

Control computer

A computer with software from the manufacturer provides constant control of aerial camera settings and the shooting process. For continuous operation, the computer is equipped with a power supply (inverter) to work from the onboard network of the aircraft.

It contains a high-speed disk drive with high reliability based on Raid3 with a capacity of 2tb and above. It provides input of images from all channels on the high-speed PCI-X bus and their record on a disk in real time.

The computer is equipped with a touch-screen monitor for easy flight.

The design of the computer is integrated into a special rack equipped with dampers to reduce vibration.

Stabilizing platform

It's a specially designed platform to compensate for the angles of inclination and rotation of the fuselage in flight, while constantly maintaining the horizontal position of the camera.

It has three servos, providing stabilization of the camera along the two axes of inclination and the angle of rotation within 0.2°.

In the work for stabilization, it uses information about the angles of inclination obtained from inertial sensors and is able to automatically eliminate the angle of wear.

Inertial GPS / IMU Applanix POS AV

It provides direct geodetic binding of camera images without the use of reference points. The design includes a dual-frequency GPS receiver, angle sensors and accelerometers. It allows to restore with high accuracy the trajectory and angles of the camera at any time at least 200 times per second.

The error in determining the coordinates of the design centers 0.05 - 0.30 m.

Error in determining angles: alpha / omega (roll / pitch) 0.005° kappa (course) 0.008°.

2.3. Analysis of digital aerial photography systems software

Software is a set of system programs required for information processing and software documents for further operation of the system.

Most aerial camera manufacturers, complete with AFA, sell software to operate and process data taken with an aerial camera.

However, there is much software for aerial photography. Their appearance is due to the fact that aerial photography has many tasks. Therefore, to solve them, software developers continue to create new programs to accelerate and improve the solution of these problems.

Each of today's existing software was created for specific tasks:

- Construction of the route;
- Monitoring the parameters of aerial photography equipment;
- File conversion;
- Processing of collected data;
- Construction of three-dimensional models and more.

WinMP is software developed by the German company IGImbH for planning and creating survey protocols and other types of aviation work.

WinMP is a program for flight planning, creation and editing of both single routes and plane shooting. The flight plan created by WinMP can consist of individual sensor trigger points, routes from one or more segments, graphic polygons and icons. The user can set them in graphical mode using the mouse or keyboard.

Planning is done using topographic maps and other cartographic information. In addition, WinMP includes support for working with DTM (DTM - digital terrain model) to automatically assess the surface and scale the resulting images depending on altitude and terrain. The program supports various models of sensors, including user-configured. Together with the program, IGI provides more than one hundred local coordinate systems for more than 70 countries. Thus, planning can be performed in a local or geographical coordinate system with sequential automatic transformation of routes into the WGS 84 system.

WinMP allows to directly download the prepared data to the CCNS (Computer Controlled Navigation System). And also read the data on the operation of the camera after shooting. All data is stored in the database and can be selected from it by various criteria:

• Shooting ID;

• Location of images;

• Project name;

• Route, etc.

This feature greatly simplifies the search for the necessary information.

Documentation of the obtained data is possible at any stage of planning or after the survey. WinMP allows to create and print reports and graphs designed according to the requirements of the end user.

The program has a modular structure and is configured according to customer requirements.

Another program for scheduling and managing shooting is MAPS. This program is developed by the Canadian company Optech Inc.

Altexis software is software developed by the Russian company GeoLIDAR.

This software is designed to perform basic thematic processing of laser-location data obtained during aerial scanning.

The user of this software becomes available:

- Execution of tasks of express processing: data viewing and quality control of shooting
- Carry out correction of laser data
- Integrate the scanner calibration module and the camera calibration module
- Sell the classification of points
- Perform tasks on infenterization of power lines (power lines)
- Decrypt and vector objects
- Export all types of data at any stage of processing to external media

The advantages of this software are support for different types of data:

- Laser scanning (or any accurate data in a planned or geographic coordinate system)
- Aerial photography data
- Raster maps of the area
- Surface models
- Vector objects
- Power line models

This software also allows you to visualize any set of data in a single window or group of linked windows at the same time. Simultaneous work with different shooting areas is available. The program provides a variety of data perspectives, due to the presence of a profile window and complex spatial filters.

Altexis supports standard ASPRS LAS format, BIN format, as well as arbitrary ASCII table format. The program has support for the POSProc trajectory.

CaptureOne software allows you to pierce the primary processing of shooting results.

This program allows you to convert photos from RAW format to standard JPEG or TIFF formats for further viewing on regular digital media.

CaptureOne was developed by the German company PhaseOne. The program is used not only for processing art photography, but also aerial photographs. The program has the ability to format images with a fairly high dynamic range, because it supports 16bit TIFF. It is also convenient with the ability to adjust the image quality, which allows you to return information from overexposed or darkened areas of the photo. Thus make it available for decryption. At the same time it is possible to correct the light balance manually or automatically.

But one of the biggest advantages of CaptureOne is the possibility of serial processing, i.e. the imposition of settings for the correction of one image on all, which significantly saves time on the processing of an entire series of images.

The Control6008 software was developed by the German company Rollei Engineering and is designed to control the camera during aerial photography.

This software allows you to create a project on disk and keep reports on the operation of the camera at the same time. In the process of work gives an indication of problems with the equipment.

You can change the shooting settings with Control6008. Expose manually or automatically, take single shots and serial at intervals. The program is able to automatically control the exposure due to the presence of the camera's exposure meter and data selection from it.

Another software is DAViS, developed by Canadian company Optech Inc.

The main advantage of this software is the automation of its operation in all processes. That is, the program automatically processes the data after downloading the images. The program also automatically edits and visualizes images, making them ready for the end user.

Georef software is a development of the Russian company GeoLIDAR. The program is designed to obtain CDT files (information about the central time) of files that contain information about the elements of the external orientation of aerial photographs on the data from the laser scanner system ALTM (Airborne Laser Terrain Mapper).

This software is useful because it calculates the values of the elements of the internal orientation of aerial photographs according to the navigation system of the laser scanner ALTM. The program works in UTM, SpecialSK and SK42 coordinates.

Georef automatically calculates TimeShift, ie corrects the inaccuracy of the camera's time. At new start the program independently restores the last parameters specified by the user at its previous start. For the convenience of the user and to facilitate the determination of shooting parameters, the program creates a Velocity file with angular and linear speeds during the shooting of each frame.

GModeler is a development of the Russian company "Geocosmos" and is designed for data processing of air and ground laser scanning.

The program quickly processes information and forms preliminary isolines for analysis of the terrain of the model and high-quality construction of structural lines of the scanned area. She is also able to form ZD models of the captured area and texture this model with growth images and photographs. GModeler can make a video presentation from the made ZD models. You can also use this software to create three-dimensional plans and drawings.

The obvious advantages of this software are a user-friendly interface, as close as possible to AutoCAD. It is even possible to use it with this program. After all, GModeler does not replace the functions of AutoCAD, but on the contrary, complements them, while providing solutions to those problems, the solution of which within AutoCAD causes certain difficulties or is not possible at all.

The program is quite powerful, so loading a large number of laser points and their filtering, classification and topological analysis of the connection will be performed quickly and easily.

It is also possible to build 3D polylines with reference to the model. For example, road contours, slopes or other structural relief lines and the ability to build profile lines and vertical sections of models, for convenience in the further use and analysis of model images.

Photocutter is a Russian program created by GeoLIDAR. It is designed to convey orthophotoplanes in correctly oriented squares based on geo-linked aerial photographs.

At the end of the use of this program are formed sheets of orthophotoplan with specified dimensions that do not require females transparency. Each letter has an attachment file.

This software works with * bmp and * jpg formats. In this case, the user has the opportunity to "compress" the files to the desired size. The user can also set the size of the sides of the original end sheets and the pixel size. The program performs envelope processing.

OffsetterSPP is software designed to measure the parameters of a scanner unit and a digital camera. The program was acquired by the Russian company GeoLLIDAR and allows you to calculate corrections to determine the center of the scanner mirror, which is used to measure offset parameters. This software also helps to calculate the position of the camera relative to the scanner unit.

With this program you can calculate the extension of the scanner and cameras. The software allows you to graphically display the relative position of the scanner, antenna and camera. It is also possible to calculate the offset parameters of the scanner on two different data sets.

POSPac is a multi-purpose software package developed by the Canadian company Applanix Corp., to handle the resulting kinematic and static measurements.

The main modules of the system are:

• POSGPS - for GPS data processing

• POSProc - to calculate the smoothed trajectory using data from the IMU

• POSEO - to determine the external orientation of aerial photographs.

The program allows the use of ionospheric models, exact ephemeris (exact coordinates of the observer). The system works with an accuracy of several centimeters. Calculates or enables the user to independently control navigation and trajectories.

ProjectionGL software is perhaps the most successful and smart of all. This program is a development of the Russian company GeoLIDAR.

The program georeferences the obtained digital aerial photographs to a digital terrain model created on the basis of laser scanning on a plane obtained by estimating the average altitude of the terrain.

ProjectionGL performs pipelined image processing, which takes 10-20 seconds to process, depending on the power of the computer.

The user can adjust the pixel size and quality of the photo and instantly frame the image.

REALM is a multifunctional program developed by the Canadian company Optech Inc.

This software is designed specifically for fast, accurate and efficient processing. You can list and convert coordinate systems.

It can process one or more data pieces or the whole project at once.

Also, the software can create a three-dimensional plan of exit points.

STARS is software developed for static analysis of results and compilation of reports, developed by the Canadian company Optech Inc.

The software creates projects, missions and flight path reports, and is designed to track the process of capturing and maintaining the system.

Transformer is designed to transform laser scanning data, trajectory and external orientation files of the camera. The program is a development of the Russian company GeoLIDAR.

Serves for:

- Quickly transform any type of special data into a local coordinate system at the appropriate pairs of points.

- Convert data from one ellipsoid to another.

- Carrying out height correction from ellipsoidal to orthometric.

The main advantages of the program are the rapid transformation of data in streaming mode into a local coordinate system for the corresponding pairs of points. It works with many formats. It creates a graphical visualization of interrelated data.

CHAPTER 3
METHODS FOR DETERMINING THE EFFICIENCY OF A DIGITAL AERIAL CAMERA

3.1. Resolution

Resolution is the ability of an optical system to separate two points from each other. [4, 5]

If aberrations are completely absent in the system, then light diffraction sets the resolution limit. The influence of light diffraction on the resolution and the theory of the latter are considered in physical optics.

To find the resolution of the lens, we will use the formula for the resolved angular distance for self-luminous objects:

$$sin\phi = \frac{1{,}22\lambda}{D}, \tag{3.1}$$

where D is the diameter of the entrance pupil. This formula corresponds to the position of the diffraction rings in the image when the first dark ring of one circle passes through the center of the other.

The maximum spectral sensitivity of the eye corresponds to λ = 560 μm. Substitutes λ in (3.1), expressing the angle ϕ in seconds, and the diameter of the entrance pupil in millimeters, will have the known formula that determines the resolution of the objective (in seconds):

$$\phi = \frac{140}{D} \tag{3.2}$$

In some cases, for example in geodesy, they take:

$$\phi = \frac{122}{D} \tag{3.3}$$

Experience has shown the validity of this formula. Real optical systems have not surpassed this limit, but many geodetic and astronomical lenses have reached it.

When considering the required resolution of the telescopes, the resolution of the eye must be taken into account. The eye resolution is usually considered to be 60", although studies indicate significantly greater eye capabilities. So, for example, the eye distinguishes black strokes on a white background even when their angular magnitude reaches 6". We have the necessary resolution of the telescope (in seconds):

$$\phi = \frac{60}{\Gamma} \tag{3.4}$$

Taking into account (3.3), we obtain the relationship between the diameter of the inlet and the apparent magnification of the telescope, i.e. formula for useful telescope magnification:

$$\Gamma_{\Pi} = 0{,}5D \tag{3.5}$$

In fact, for geodetic telescopes, for which the full use of the eye's resolution is especially important, there is, on average, a relationship between the diameter of the inlet and the apparent magnification (according to German telescopes):

$$\Gamma_{\Pi} = 0{,}74D \tag{3.6}$$

The resolution of telescopic systems is always evaluated in angular measure. In fig. 3.2 shows the characteristic curve of the resolution of the main tube of a triangulated theodolite, measured when observing without a filter. The asymmetry of the resolution curve is an indicator of the misalignment of the optical system.

The resolution of photographic lenses is measured in lines per millimeter. Obviously, the resolved distance will be equal to the product of the lens focal length by the tangent of the resolved angle ϕ:

$$\delta = f' tg\phi, \tag{3.7}$$

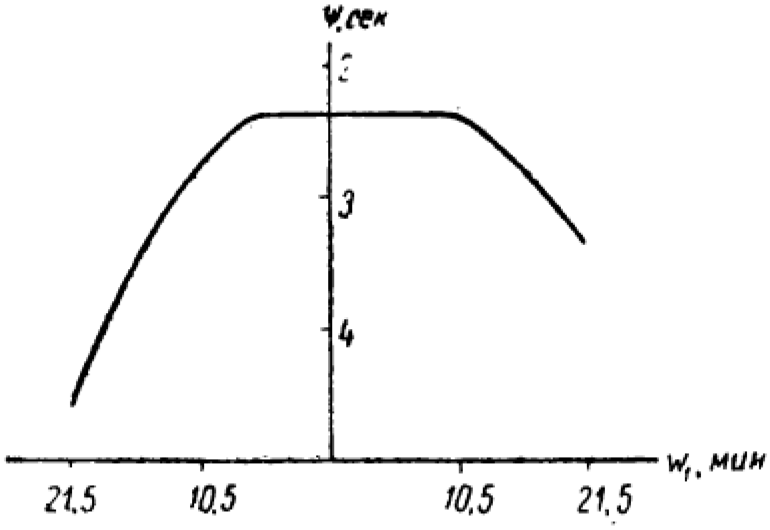

Fig. 3.1 Resolution of the main pipe

Given the small values of the angles, we replace the tangent with a sine, then substitute sinϕ from this formula in (3.1) and go to the number of lines (dashes) per millimeter:

$$N = \frac{1}{\delta} = \frac{D}{1,22\lambda f'}$$

Taking λ = 0.00056 mm, we get:

$$N = \frac{1473}{\forall} \tag{3.8}$$

i.e. the resolution of a photographic lens depends on the relative aperture. Experience has shown that photographic lenses largely fall short of this limit. The main reason is their significant aberrations and insufficient resolution of the photo layer.

Most lenses have a resolution of about 25-30 lines per millimeter at the center of the field.

Resolution is considered not only in the center of the field, but also over the entire field of the image. The characteristic curve of the resolution of one of the photographic lenses is shown in Fig. 3.2; the test was carried out on a fine-grained film. The ordinate is the resolution numbers, and the abscissa is the angles of the field of view or the size of the image.

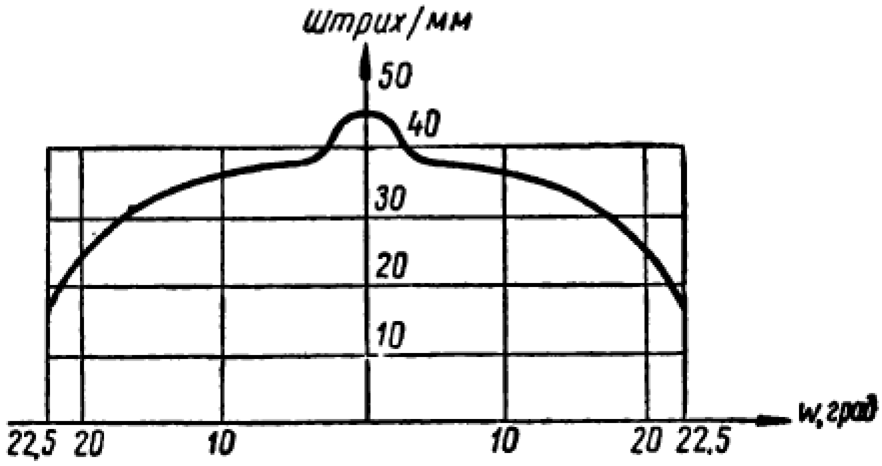

Fig. 3.2 Graph of the resolution of a photographic lens f '= 600 mm, relative aperture 1 16, shooting scale 1:10

The resolution of optical devices is determined using test objects of absolute contrast in the form of the so-called patterns. There are dashed (Figure 3.3, a) and radial (Figure 3.3, b) patterns. A line pattern is a group of misplaced stroke families. The strokes of the four families are oriented at an angle of 45 degrees to each other. Within the same family, strokes are parallel and the same width. There are usually 16 or 25 such groups of families. The width of the strokes from group to group grows exponentially.

There is a simple relationship between the midpoints of any pairs of strokes of the same name and the resolution in the angular measure:

$$\delta = p \tan \phi, \tag{3.9}$$

or

$$\delta = f' \tan \phi. \tag{3.10}$$

The pattern can be directly observed at a distance p from the eye or the objective of the instrument under test, or mounted in the focal plane of a collimator objective with f'.

Resolution N in the latter case will be determined by the formula:

$$N = \frac{1}{f' \tan \phi} \quad (3.11)$$

The dashed pattern is very convenient for practical measurements of the resolution of any optical devices.

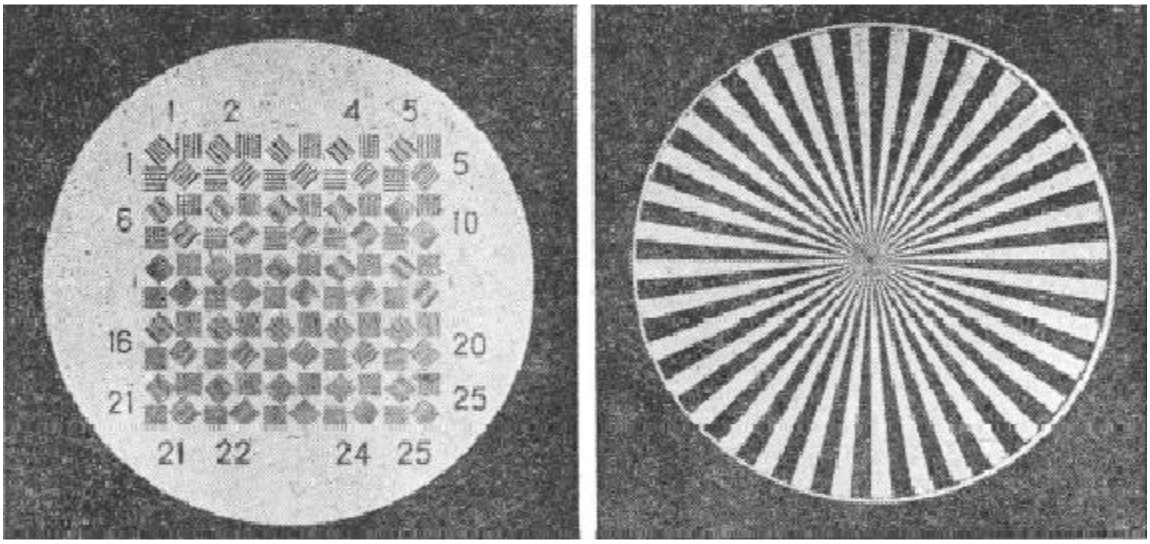

Fig. 3.3 Patterns: a – dashed, b – radial

The radial pattern is primarily used for testing photographic lenses. Let us assume that the diameter of the permitted circle is D. There are m black strokes within the circumference πD. As before, the distance between the centers of black (or white) strokes is taken as the resolution value. Hence the stroke width:

$$d = \frac{\pi D}{2m}, \quad (3.12)$$

in distance of resolution:

$$\delta = \frac{\pi D}{m}, \quad (3.13)$$

Passing to the number of strokes per mm, it turns out:

$$N = \frac{m}{\pi D}. \quad (3.14)$$

The diffraction theory of image formation in a microscope makes it possible to indicate the limits of resolution of objects located at a finite distance from the optical system. In most cases, the resolution conditions for self-illuminated objects are similar to those for uniformly illuminated objects.

The smallest object or detail of an object that can be resolved in a microscope is determined by the equation:

$$d \geq \frac{\lambda}{2A}. \quad (3.15)$$

The resolution of a microscope-type optical system is proportional to the aperture A.

3.2. The visual properties of the aerial photographic lens

The optical image of a point, built by the lens, is an unsharp, blurry spot, which affects the possibility of separate reproduction of fine details in an aerial photograph. This is due to the presence of residual lens aberrations and diffraction, which disturbs rectilinear light propagation and creates a complex illumination distribution in the image plane. In this regard, the point is depicted as a spot surrounded by diffraction rings with decreasing brightness. The radius of the diffraction ring is a function of the wavelength and relative aperture of the objective

$$r = F(\lambda, n_0)\ . \quad (3.16)$$

When passing through the optical system, the diffracted wave front of an infinitely distant object deviates from the primary front by an angle ϕ with a path difference equal to $\Delta = 1.22\lambda$ (Fig. 3.4). [4, 5]

The lens, during the passage of which the deformation of the wave surface does not exceed a quarter of the wavelength, is considered ideal.

The illumination of the spot changes from a maximum at point O to zero at point B, and this increase occurs in proportion to an increase in the path difference from 0 to 1.22λ.

In this regard, the radius of the dark ring will be equal to:

$$r = f'\phi = \frac{1{,}22\lambda}{D} * f' = \frac{0{,}61\lambda}{u}, \quad (3.17)$$

where D is the diameter of the effective aperture of the objective; u is the aperture angle.

For the average value of the wavelength of the visible spectrum λ = 0.555 μm, in the casting measure it is equal to:

$$r = \frac{0{,}34}{u}\ \mu\text{m}. \qquad (3.18)$$

It is known that the eye sees two points of the image plane separately at the required brightness difference in the middle of the diffraction spots and at the point of their contact. Such sensitivity of the eye is called contrast sensitivity and for the average eye is equal to 5% with the ratio of illumination at the minimum point to the maximum point equal to 85%.

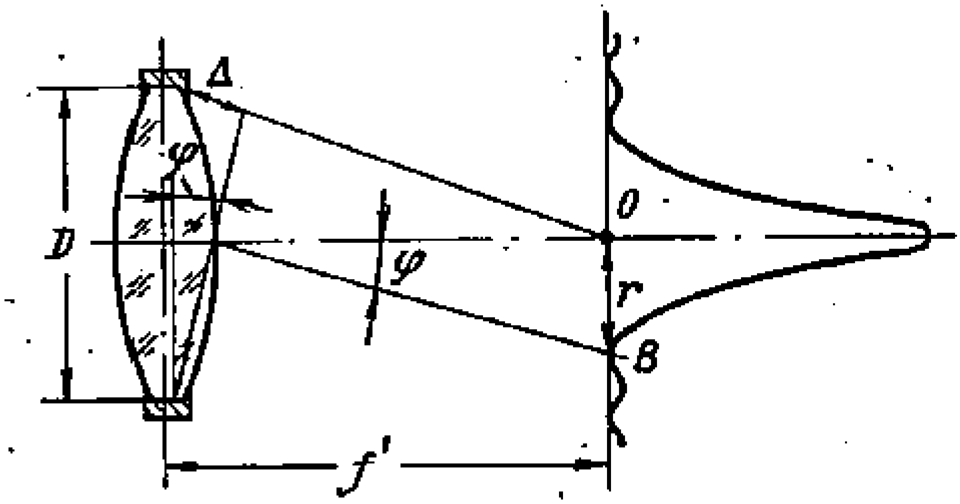

Fig. 3.4 Deviation of the front of a wave coming from an infinitely distant point

From the above formulas (3.17), (3.18) it follows that the radius of the first dark ring at a constant wavelength of light depends on the relative aperture of the objective $n_0 = \frac{D_0}{f'}$. There is some optimal aperture ratio at which the best correlation of the effects of diffraction and aberration on image quality is observed. According to research for aerial lenses, this aperture is in the range of 1 : 4÷1 : 11.

Obviously, the estimation of the image construction according to the formulas given will be approximate and insufficient. To assess the image quality, other methods and criteria are used that make it possible to characterize the optical system in combination with an image receiver, in this case a photographic layer.

Currently, two criteria are used to assess image quality: resolution (R, mm^{-1}) and transfer function P (N), mm^{-1}.

The resolving power of an optical system is the property of an optical system to separately depict two closely spaced points or lines. Resolution is expressed by the number of lines separately transmitted per 1 mm of the image, and is indicated in lin / mm or mm^{-1}. In the case when the resolution is expressed in angular measure, it is called the visual power of the lens and is calculated by the formula:

$$tg\phi'' = \frac{\cos^2 \omega}{f' R_0}. \quad (3.19)$$

As a result of the interaction of the lens and the photosensitive layer, the photographic resolution of the system is obtained, which is the main characteristic of an aerial camera. The resolution of aerial photographic lenses and photographic systems is determined using standard line patterns. The resolution of the lens is determined visually. The angular distance between the axes of adjacent strips is γ’’=206265, and the number of stripes in one millimeter of any element is determined from the expression:

$$N = \frac{60}{B} * K_n, \quad (3.20)$$

where N is the number of lines in 1 mm; B - the length of the pattern base in mm, the distance between the marks of elements 3 and 23, 11 and 15; K = 1.06 (n -1) - coefficient depending on the number n of patterns.

Patterns are distinguished by numbers. The numerical values of the parameters of patterns from No. 1 to No. 5 are given in table 3.1.

Standard patterns have an absolute contrast of one. By contrast, patterns mean the ratio of the difference between the maximum and minimum illumination (E_{max}, E_{min}) to the maximum illumination:

$$K = \frac{E_{max} - E_{min}}{E_{max}}. \quad (3.21)$$

Table 3.1

The numerical values of the parameters of patterns

Длина базы	Номер мир					Длина базы	Номер мир				
	1	2	3	4	5		1	2	3	4	5
B	1,2	2,4	4,8	9,6	19,2	*b*	1,14	2,27	4,55	9,07	18,02
d	0,219	0,438	0,877	1,75	3,51	*m*	0,05	0,1	0,2	0,4	0,8
C	0,01	0,02	0,04	0,08	0,16	*S*	0,005	0,01	0,02	0,04	0,08

Along with the line pattern, the radial pattern is often found. Depending on the patterns used, the resolution is determined by the formulas:

1) for line patterns

$$R_0 = \frac{f\prime}{l_0 F}, \tag{3.22}$$

2) for radial patterns

$$R_0 = \frac{N_K}{\pi d_K}, \tag{3.23}$$

where l is the width of the lines in the original patterns; d is the diameter of the circle of confusion in the center of the pattern image, measured on the device; N is the total number of lines of the radial pattern; f 'and F are focal lengths, respectively, of the studied objective and the collimator objective.

3.3. Frequency-contrast characteristic

Frequency-contrast characteristic (FCC), that is, the function of transmitting modulation in optics and photography is one of the parameters that characterize the quality of the image reproducing system. The digital aerial camera consists of a lens, a matrix, a processing channel and a display (Fig. 3.5):

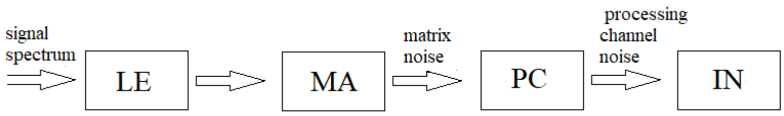

Fig. 3.5 Mathematical frequency model

The FCC of a digital camera is a product of the FCC of a lens, matrix, processing channel, and indicator (display):

$$W_S(\upsilon) = W_{LE}(\upsilon) W_{MA}(\upsilon) W_{PC}(\upsilon) W_{IN}(\upsilon). \tag{3.24}$$

The FCC, as well as the signal-to-noise ratio, allows to estimate the resolution of digital camera [6] .

Today, to evaluate the quality of the aerial photography system, there are two methods of determination the resolution of the equipment: full-scale and laboratory. The first method is represented by laying the test object on the surface of the plane over which the aircraft is flying. This is a very costly method, so the quality of the photo and video image is checked on the indicator by means of electronic tests (reproduction of color stripes and straightness of inclined lines) formed by FMS (Flight Management System). In this case, we only check the effect on the image quality of the processing channel and the display (indicator), i.e. the effect of the lens and the matrix on the image quality is not evaluated, i.e. there is no way to know the quality of the digital aerial camera. The second method makes it possible to evaluate the impact of image quality on the whole system, but it requires sufficient time and equipment, so it is not used in aviation. This so-called ‘light-to-light’ method allows you to evaluate the quality of an image from an image object to the reproduction of its image on the indicator (display).

Controlling the image quality of lenses by FCC is of considerable interest to researchers, in particular, in relation to high-quality cinematographic and photographic lenses.

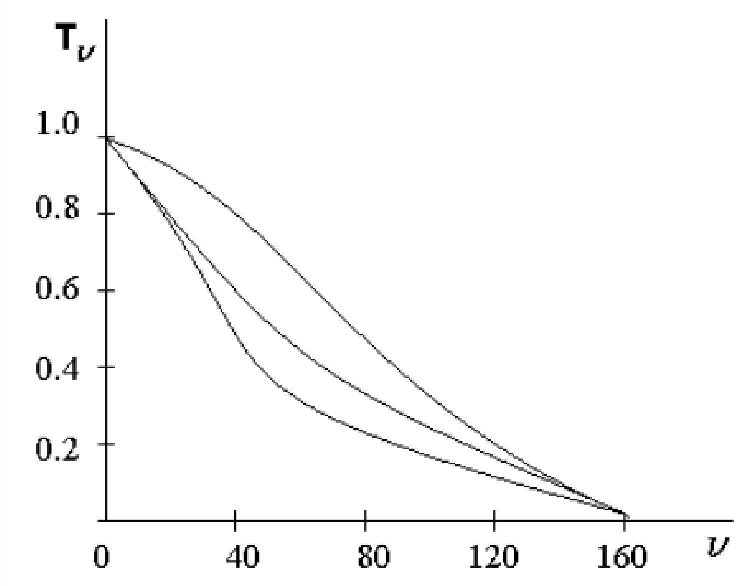

Fig. 3.6 FCC plot

Shown in fig. 3.5 FCC plots of three different lenses show that all of these lenses have the same resolution limit (n = 200 mm^{-1}), where n are the spatial frequency values plotted on the abscissa axis of the plot, the ordinate plotted relative contrast or contrast transfer coefficient:

$$T = \frac{K\prime}{K} \tag{3.25}$$

where K and K 'are the contrasts of the object and the image, respectively.

At the same time, objective A produces the most contrasting of the three images at midrange frequencies, which is perceived as the best of the three in normal viewing.

FCC can be measured as:

$$T(\nu) = \frac{K\prime}{K} = \frac{\frac{E\prime_{max} - E\prime_{min}}{E\prime_{max} + E\prime_{min}}}{\frac{B_{max} - B_{min}}{B_{max} + B_{min}}}, \tag{3.26}$$

where E'_{max} and E'_{min} are the maximum and minimum illumination in the image, B_{max} and B_{min} are the maximum and minimum brightness of the object.

The results of measuring the FCC of lenses are influenced by a number of factors associated with the calculation of their optical systems: residual monochromatic and chromatic aberrations, light scattering, centering quality, etc. All these disadvantages lead to a decrease in the contrast transmission coefficient and worsen the transmission of structural elements of the object in the image.

When monitoring serial production lenses, to reduce the volume of measurements, FCC values are determined only at one or two spatial frequencies, for example, for cine lenses n = 20 mm^{-1} and n = 40 mm^{-1}. Measurements are taken in the center of the fieldб along the field and at the edge of the frame in the meridian and sagittal directions. The quality of lenses is judged by the lowest contrast value.

MTF can be measured in white or monochromatic light for the e line (λ = 546.1nm) with a fully open diaphragm, as well as with aperture up to 1 : 4 ... 1 : 5.6.

A barely noticeable change in the image quality corresponds to a 20% change in the contrast transfer coefficient at a given frequency. This value is taken as a permissible deviation in assessing the quality of lenses according to the contrast transfer coefficient criterion.

Direct reading of FCC in measurements involves the use of sinusoidal test objects, the manufacture of which is associated with significant difficulties. Therefore, in practice, a test object in the form of a U-shaped world is used. Moreover, harmonics are isolated in the electronic part of the measuring equipment by passing the signal through a narrow-band frequency filter, what, naturally, generates additional errors. The control requires a sophisticated design of electro-optical installations that require highly qualified maintenance and are often unstable in operation, which hinders the widespread introduction of lens control by FCC.

The spatial frequencies of the test object and its image are determined by the formulas:

$$\nu = \frac{f_{м0}}{f'_{л}} \nu y \quad (3.27)$$

$$\nu' = \frac{\nu y}{\beta}, \quad (3.28)$$

where $f_л$ и $f_м$ is the focal length of the achromatic lens and microlens, respectively; ν - frequency of strokes applied to the cylindrical surface of the test 10, 55, 1.1, 2.2 mm: β - magnification of the test objective.

A large number of designs of installations for measuring MTF are known. The installations that are most simple to manufacture and operate are found in use.

At the same time, to date, a single criterion has not been developed that allows the FCC to unambiguously characterize the quality of the lens, consistent with the visual perception of the image.

Despite the more than 40-year history of the development of the technique for measuring the FCC, there is a discrepancy in the results of measuring the MTF of the same objectives on installations of different designs.

At the same time, as experience shows, measurement of PSF and RFL, especially when using isophotometric technique, gives results with reproducibility of at least 3%, which allows you to calculate the FCC quite accurately, and most importantly - unambiguously.

Thus, as a promising direction in the development of techniques for monitoring and certifying the image quality of lenses, it is of interest to develop methods and equipment for isophotometric measurement of PSF and PSL with data output on a computer to obtain the required image quality characteristics.

CHAPTER 4

LABORATORY TESTING OF A DIGITAL CAMERA

4.1. Methods for determining the resolution of a digital aerial camera

Equipment for determining the resolution of a digital aerial camera

The study of the resolution of the aerial camera is carried out on the installation shown in Fig. 4.1.

The installation includes an optical bench and an aerial camera.

The aerial camera is mounted on a movable channel and together with it can rotate to the right and left relative to the zero position of the optical bench axis at an angle of 55°.

The optical bench is a combination of the following main elements: a light source 3, a condenser 4, a diaphragm 5, a set of light filters 2, milky and frosted glass 1, a test pattern 6, a collimator objective 7 and a tube 8.

The light source, condenser and diaphragm form an illuminator designed to illuminate the world. The intensity of the luminous flux can be changed using the diaphragm of the illuminator.

A set of light filters is designed to highlight the required part of the illuminator's radiation spectrum, and milky and frosted glass - to ensure uniform illumination of the world.

The optical bench tube is retractable and provides a change in the position of the target relative to the collimator lens.

The optical bench allows the study of aerial cameras with focal lengths from 100 to 1000 mm and provides photographing of the test target in a beam of parallel beams, which corresponds to its location at an infinitely large distance from the aerial camera. Test pattern 6 is in focus of the collimator lens 7.

To determine the resolution of optical systems, dashed and radial patterns are used. Line patterns have 30 elements, each of which consists of four squares with strokes in different directions. The width of the stripes of each pattern decreases from element 1 to element 30 according to the law of a geometric progression. Radial patterns consist of a circle on glass that is divided into 36 or 72 transparent (white) and opaque (black) sectors.

This laboratory setup uses a line and radial patterns, but a line pattern is sufficient to determine the resolution.

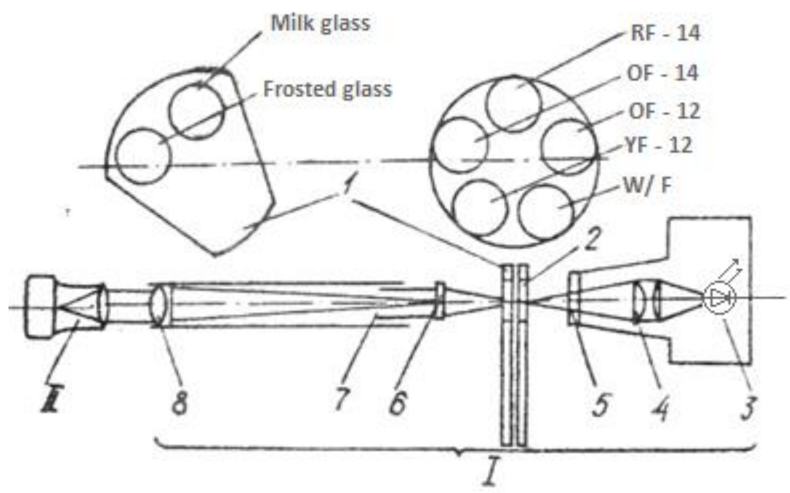

Fig. 4.1 Laboratory setup diagram

The pattern is attached to a telescopic tube and, within certain limits, can move along the axis of the collimator.

The optical bench is designed for the study of optical and optoelectronic systems, as well as individual optical parts for image quality, for measuring optical and spatial and energy characteristics.

The optical bench can be used for marketing, assembly and alignment of various optical systems, for demonstration, educational and research work.

The design and equipment of the optical bench make it possible to center well and maintain the consistency of centering the optical axis of the parts to be inspected with the optical axis of the measuring units included in the bench set, in order to then carry out measurements by methods developed based on the laws of geometric optics.

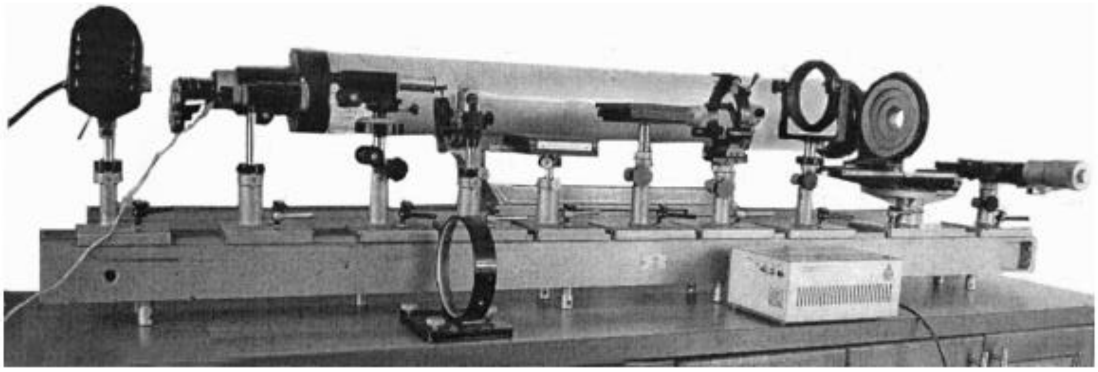

Fig. 4.2 General view of the optical bench fixtures

The optical bench is equipped with a number of tables and holders for attaching round parts, prisms, mirrors, ready-made telescopic and other systems, various types of illuminators, tables with micrometric converters, which are precision instruments and are designed for universal use during operation.

All tables, holders and other elements and devices can be fixed on the bed in the required order, depending on the nature of the work.

Standard line patterns are glass plates on which 25 elements are applied, digitized along the edges. Each of the 25 elements consists of four groups of parallel light stripes of equal width and length against a black background. The groups of strokes in each element are located in four directions: horizontal, vertical, and at 45° angles to the first two. The width of one stroke is understood as the distance between two adjacent dark or light strokes, that is, the dark and light stripes make up one stroke. The width of the strokes decreases from element to element according to the law of a geometric progression with a denominator equal to 0.94. The angular distance between the axes of adjacent strips is equal to y = 206 265, and the number of stripes in one millimeter of any element is determined from the expression (3.20).

Equipment for determining the FCC of a digital aerial camera

To determine the contrast ratio of a digital camera, a laboratory unit, consisting of two tripods and an optical shaft, is required. The first tripod has a platform for mounting a digital camera, and the second has a holder for attaching the printed table EIA1956. Both tripods can move along the optical shaft and adjust the height of the tripod itself.

The laboratory unit is as follows (Fig. 4.18). The table itself looks like this (Fig. 4.19):

Fig. 4.3 The laboratory unit

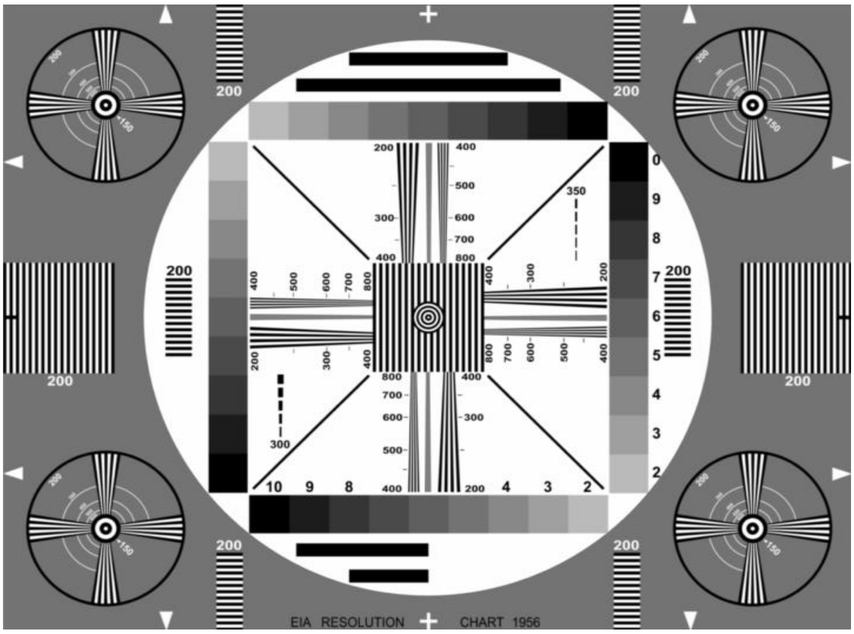

Fig. 4.4 Test table (measure EIA1956).

4.2. Research of the resolution of aerial photo camera

To determine the resolution of aerial photo camera it is necessary to:

1. Prepare the aerial camera for work;
2. set APC shutter speed and illuminator aperture;

3. turn on the optical bench illuminator;

4. expose the pattern at an angle of deviation of the optical axis of the APC from the axis of the collimator of the optical bench, equal to 0 ° at relative apertures of the lens;

5. calculate the resolution of the aerial photosystem using the formulas;

6. enter the results of measurements and calculations in table 4.1.

To determine the resolution of the aerial photosystem in within its angle of view, it is necessary:

- set the aperture of the aerial photographic lens, APC shutter speed and aperture of the illuminator;
- expose the pattern at certain angles of deviation.
- calculate the resolution of the aerial photosystem using the formulas;
- enter the results of measurements and calculations in table 4.2.

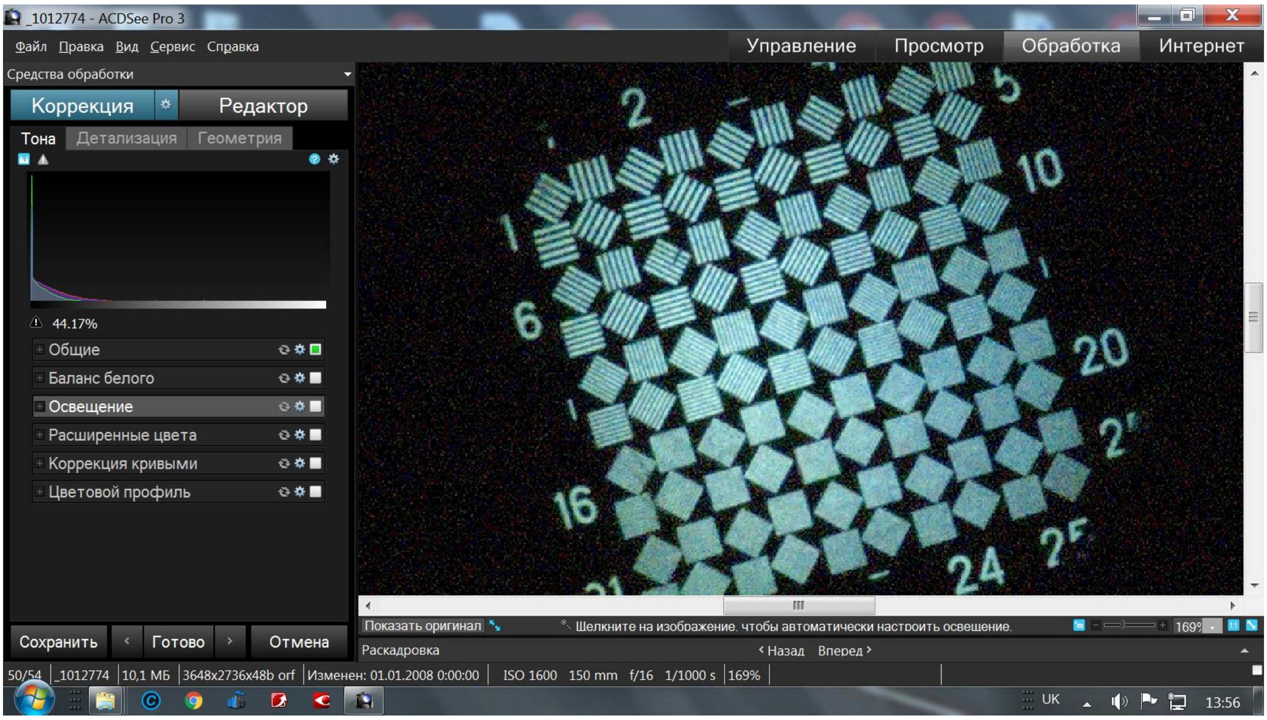

Fig. 4.5 Pattern image

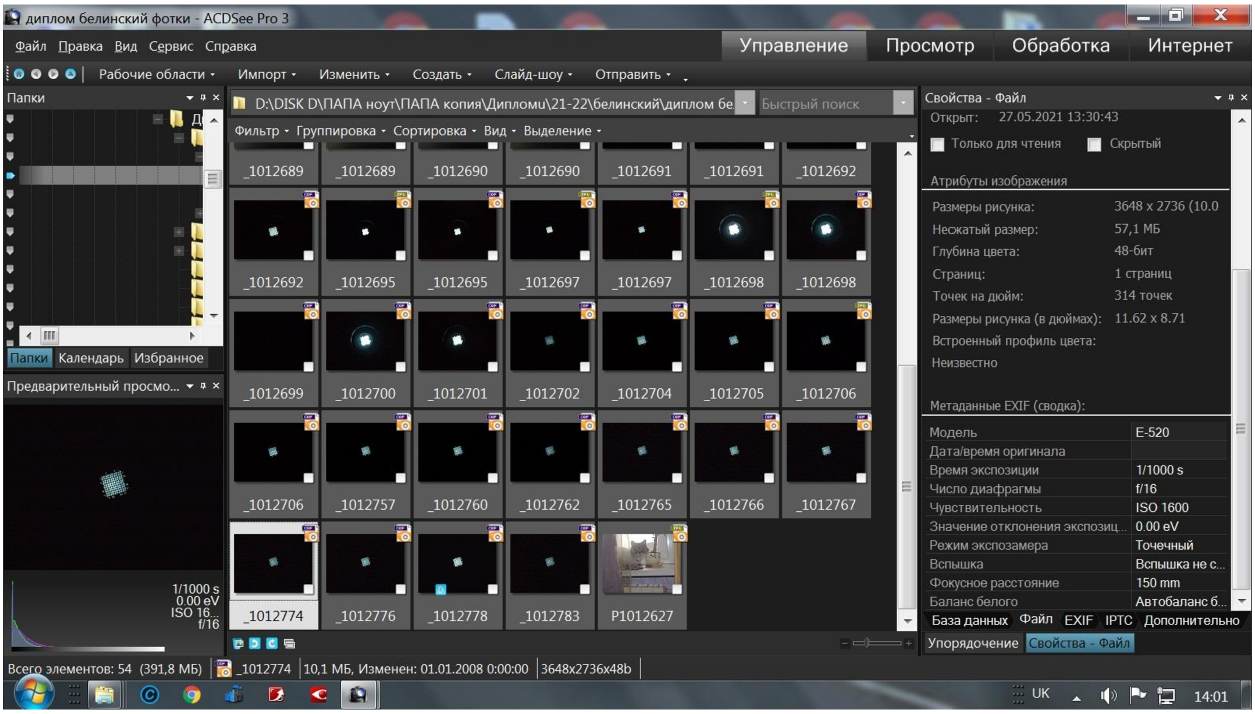

Fig. 4.6 Characteristics of pattern image

$$R = \frac{60}{B} * 1{,}06^{N-1} * \frac{f'_{к}}{f_{об}},$$

R is the resolution of the aerial camera, mm; *B* is the pattern base, mm; *N* is the number of the pattern element (the number of the outermost visible element of the pattern); $f'_{к}$ is the focal length of the collimator, mm; $f_{об}$ is the focal length of the tested system, mm.

B = 19,2 mm

$f'_{к}$ = 1600 mm

Table 4.1

Digital aerial camera resolution table

$f_{об}$	150												
n	5,6	6,3	7,1	8	9	10	11	13	14	16	18	20	22
t,s	1/320	1/250	1/250	1/250	1/250	1/250	1/1000	1/1250	1/320	1/16	1/500	1/200	1/100
R	63,28	59,69	71,1	56,32	50,1	50,12	56,32	53,13	59,69	67,07	59,69	44,6	56,32
N	12	11	14	10	8	8	10	9	11	13	11	6	10
$f_{об}$	123												
n	5,6	6,3	7,1	8	9	10	11	13	14	16	18	20	22
t,s	1/4000	1/4000	1/4000	1/3200	1/2500	1/100	1/1600	1/800	1/4000	1/800	1/640	1/400	1/125
R	68,68	68,68	72,79	68,68	77,17	77,17	68,68	68,67	64,8	68,68	68,68	64,8	51,3
N	10	10	11	10	12	12	10	10	9	10	10	9	5
$f_{об}$	100												
n	5,6	6,3	7,1	8	9	10	11	13	14	16	18	20	22
t,s	1/1600	1/1000	1/4000	1/4000	1/1000	1/4000	1/1250	1/4000	1/4000	1/125	1/500	1/320	1/250
R	63,12	56,18	66,9	66,9	63,12	75,2	66,9	75,2	70,9	66,9	63,12	63,12	59,55
N	5	3	6	6	5	8	6	8	7	6	5	5	4

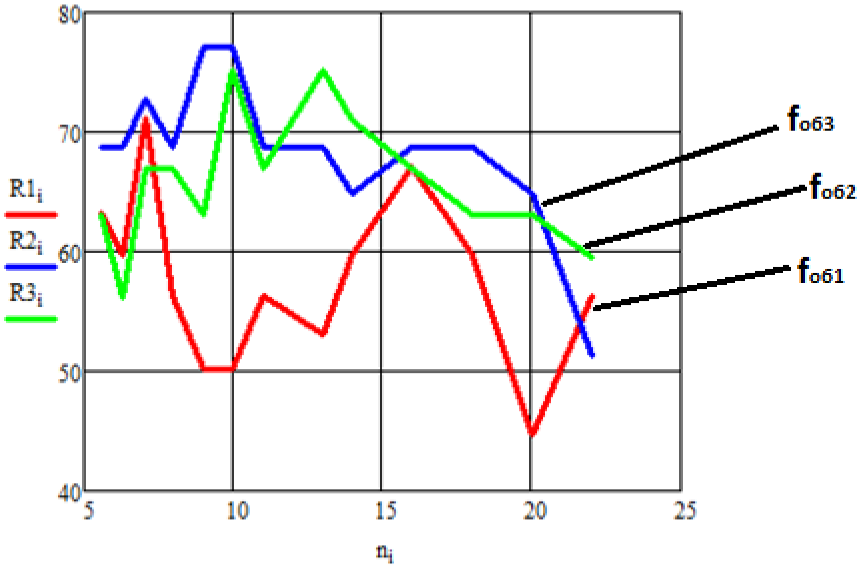

Fig. 4.7 The graph of the dependence of the resolution of the digital aerial camera on the aperture

Line patterns captured in 'A' (Aperture) mode.

For the determination of the resolution of the aerial photosystem in within its angle of view:

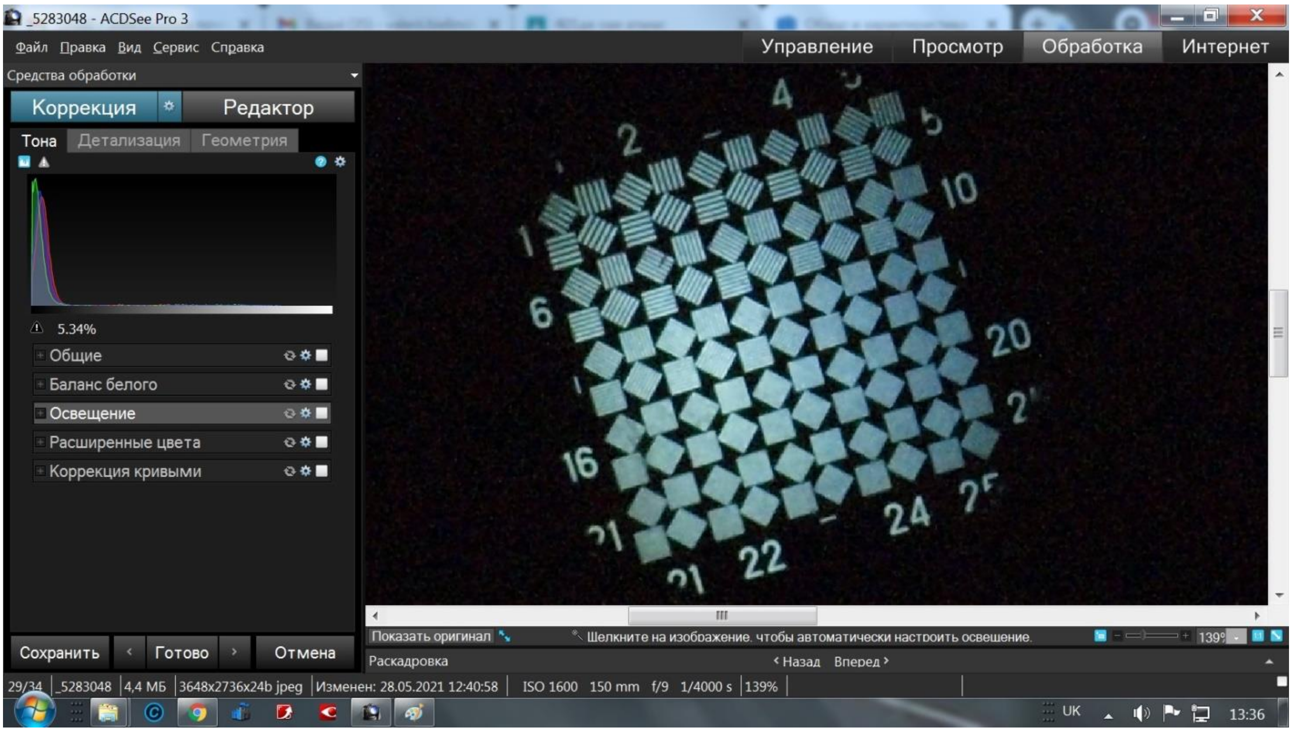

Fig. 4.8 Pattern image in within angle of view

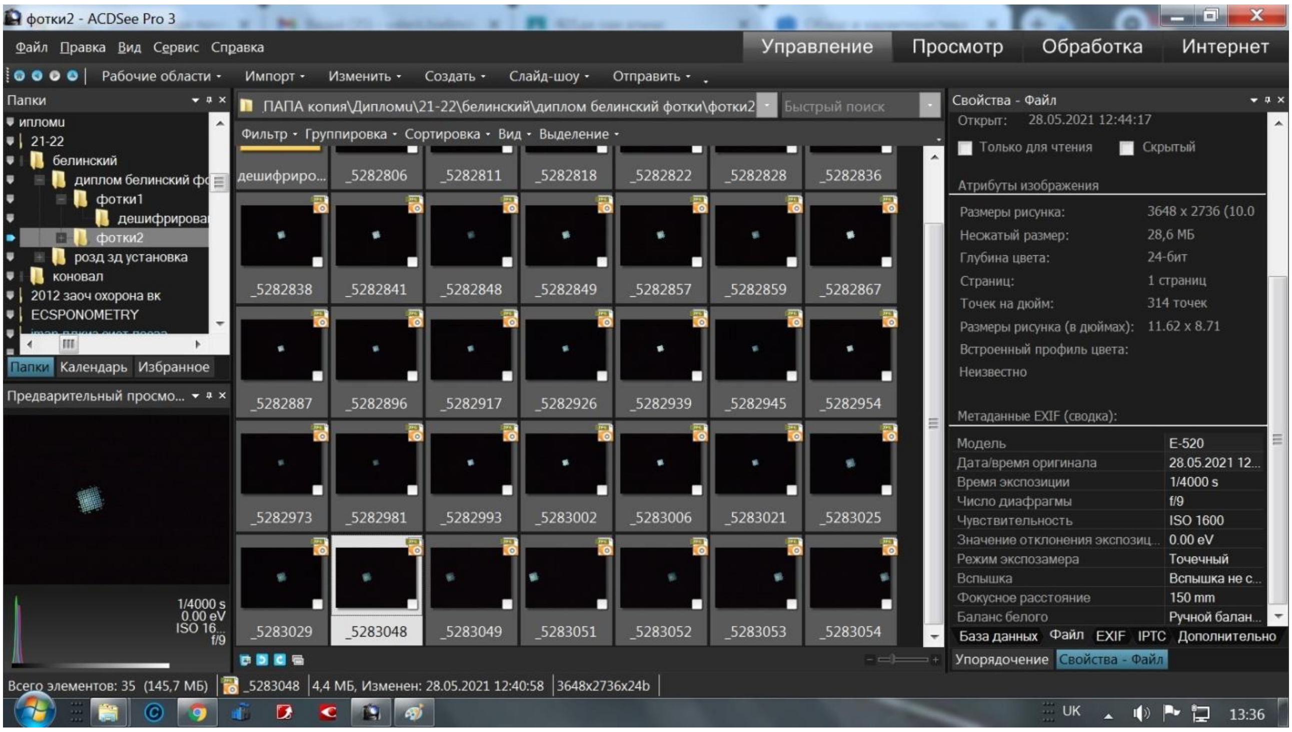

Fig. 4.9 Characteristics of pattern image in within angle of view

Table 4.2

Digital aerial camera resolution table in within angle of view

$f_{об}$	150					
n	9					
t,s	1/4000					
R	59,69	56,32	53,13	63,28	59,69	59,69
N	11	10	9	12	11	11
α	0,9	3,1	4,75	−0,9	−3,1	−4,75

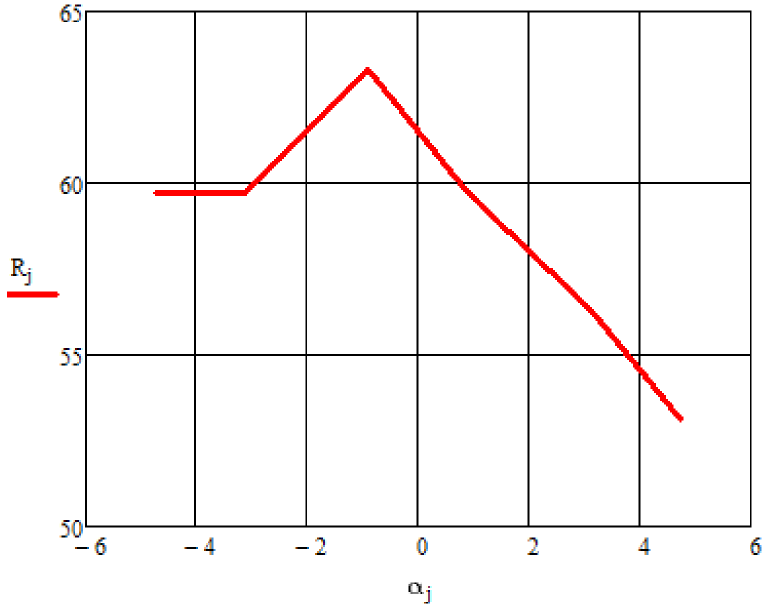

Fig. 4.10 Graph of dependence of resolution on the angle of view

Line patterns captured in 'M' (Manual) mode.

4.3. Research of FCC of aerial photo camera

To measure and calculate the frequency-contrast characteristic the next steps are:

1) affix the printed table EIA1956 on a tripod, provide sufficient and uniform illumination;

2) position the camera on another tripod so that the table image fills the entire screen horizontally at average zoom values. With the exposure set correctly, all 10 semitones should be played in the optical wedge image;

3) provide absolutely stable position of the camera and take a test photograph of the table;

4) position the camera so that the table image occupies the entire screen vertically and horizontally at the same zoom value as in point 2, and perform a photographic survey;
5) important condition when shooting: small white triangles from below, top, left and right of table (benchmarks) should touch the boundaries of the frame, not the restricted area in the viewfinder, that is, it is necessary to control the image on an external monitor with a visible area of 100% frame coverage;
6) download the test object image using the LOAD command in RightMark Video Analyzer (RMVA) utility [7];
7) by the command "ZOOM" form and define the area of the test object image for measurement;
8) go to "Region> White Sample" to determine the white level;
9) press the "Region> Vertical Regions" button and try to position 2 red areas so that they do not extend beyond the dark edges of the wedges being analyzed;
10) correct the zero brightness level in the darkest half-tone of the optical wedge;
11) use the GRAPHIC command to plot the FCC.

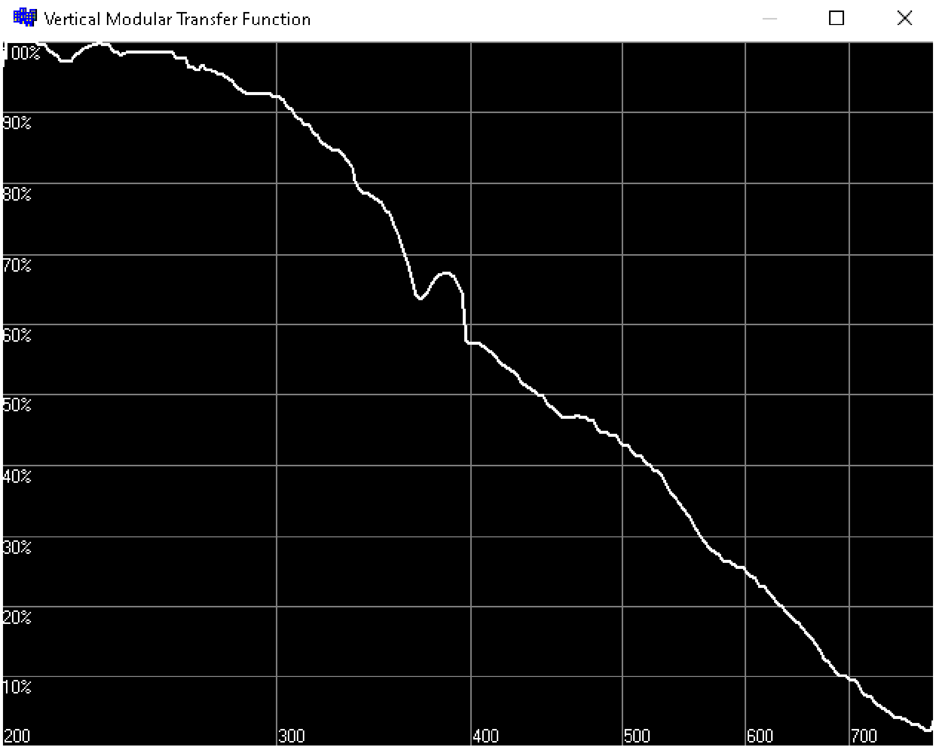

Fig. 4.11 FCC of EIA1956

The results obtained can be used to develop technological conditions for testing digital video cameras and aerial cameras.

CONCLUSION

In this thesis, the models of aerial cameras are indicated, on which aircraft they are mounted and their examples, the principle of operation of the camera, its photomatrix, and most importantly, the methods of testing AFA in laboratory conditions.

With these test methods, you can effectively test your aerial camera for performance.

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