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7 June 1982

USSR Report

CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

(FOUO 12/82)

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CONTENTS

HARDWARE

RECOMMENDED HARDWARE FOR AUTOMATED CONTROL SYSTEMS

Moscow AVTOMATIZIROVANNYYE SISTEMY UPRAVLENIYA PREDPRIYATIYAMI in Russian 1981 (signed to press 24 Mar 81) pp 166-167

[Table 6.2 from book "Automated Enterprise Control Systems", by Vladimir Alekseyevich Andreyev and Gennadiy Petrovich Penkin, Izdatel'stvo "Finansy i statistika", 20,000 copies, 248 pages]

[Text] Table 6.2. List of Hardware Recommended for Use in Automated Control Systems

Group and Type of Hardware	Classes of Hardware from Units in Series Production and Being Prepared for Production
Computers	M-4030, YeS-1022, YeS-1033, YeS-1035, YeS-1040, YeS-1050, YeS-1060
Small Computers	M5000, M6010, M6000, M7000, M400, M40, YeS-1010, Nairi-3-2
VPM [punchcard computers]	PO-80-2/2M, PA80-2/3M, PEM80, PR80/45U, PM-80, RPM80-2MS, KA80-2/2M, KA80-2/3M, SE80/2, S8L-5M/45, TA80-1, T-5M, EVP80-2, EVP-1
VKM [keyboard computer]	Iskra-11M, Iskra-12, Iskra-23, Iskra-1103, Iskra-2301, Iskra-2302, Iskra-111T, Iskra-122, Iskra-522, Iskra-1122, Bystritsa, SVD-107, SVD-108, the group of Askota-170 class bookkeeping machines, Tsellatron, Zoyemtron-383, Iskra-524, Iskra-535, Iskra-525, Iskra-526, FM-345P
External Memory Units	YeS-5010, YeS-5012, YeS-5016, YeS-5017, YeS-5019, YeS-5021, YeS-5022, R421, R412, A322-1, YeS-5051, YeS-5052, YeS-5055, YeS-5056, YeS-5058, YeS-5035, YeS-5061, YeS-5071, YeS-5027
Communications Channels, Blocks	YeS-2422, YeS-4012, YeS-4430, YeS-4035, YeS-4060, YeS-4012-01, YeS-4080

[Table 6.2, continued]

Group and Type of Hardware	Classes of Hardware from Units in Series Production and Being Prepared for Production
Input-Output Units	FS-1501, A411/4, YeS-6014, YeS-6022, YeS-6121, YeS-6122, YeS-6025, YeS-6191, R-640, YeS-6012, YeS-6013, YeS-6016, YeS-6111, PL-150, PL-80/8, A421-2, YeS-7022, YeS-7024, YeS-7122, YeS-7191, YeS-7192, R-630, YeS-7010, YeS-7012, YeS-7013, YeS-7014, YeS-7111, YeS-7112, T-63, A531-2, A531-5, YeS-7050, YeS-7051, YeS-7052, YeS-7053, YeS-7054
Data Preparation Units	YeS-9001, YeS-9020, YeS-9021, YeS-9022, YeS-9024, P80/6, YeS-9010, YeS-9011, YeS-9012, YeS-9013, SPD-9000, YeS-9015, YeS-9018, YeS-9041
Units of Remote Data Processing Systems	A542-2, A-542-6, A552-3, YeS-8001, YeS-8002, YeS-8005, YeS-8006, YeS-8010, YeS-8011, YeS-8015, YeS-8019, YeS-8025, YeS-8028, YeS-8030, YeS-8040, YeS-8060, YeS-8061, YeS-8062, YeS-8080, YeS-8121, YeS-8122, YeS-8131, YeS-8136, YeS-8140, YeS-8400, YeS-8401, MPD-2 (YeS-8402), MPD-3 (YeS-8403), MPD-1 (YeS-8410), AP-1 (YeS-8501), AP-2 (YeS-8410), AP-3 (YeS-8503), AP-4 (YeS-8504), AP-5 (YeS-8505), AP-11 (YeS-8511), AP-61 (YeS-9561), AP-62 (YeS-8562), AP-64 (YeS-8564), AP-63 (YeS-8563), AP-70 (YeS-8570), YeS-7039
Units for Direct Communication of Operator with Computer	YeS-7061, YeS-7063, YeS-7064, YeS-7066, YeS-7566, YeS-7902, YeS-7906, YeS-7071, YeS-7073, YeS-7074, YeS-7172, YeS-7173, YeS-7174
Printers	ATsPU-128-2M, ATsPU-128-3M, A531-3, YeS-7030, YeS-7031, YeS-7032, YeS-7033, YeS-7034, YeS-7035, YeS-7038
Peripheral Equipment	RP-10, RP-11, RP-20, RP-50, RP-51, RP-100, RP-101, RI-4501, RI-4503, RI-7501, RI-7701, "EPRA-1"
Remote Data Collection and Transmission Units	RI-8901, ARP-2M, USP-1V1, USP-1G1, USP-1K1, USP-1F1, USP-1NE1, "Ekran-M", UVTL-M
Data Transmission Equipment	Akkord-50, Akkord-1200PP, APD-3M, APD-31, APD-51, APD-IV-TL, APD-IV-FL, Sbor-1, Sbor-2
Telegraphs	T-63, Rioni
Document Reader	Blank-2

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AUTOMATED SYSTEM FOR CONTROLLING TECHNOLOGICAL PROCESSES IN PRINTED-CIRCUIT BOARD PRODUCTION

Moscow PRIBORY I SISTEMY UPRAVLENIYA in Russian No 3, Mar 82 p 5

[Article by Engineer I. P. Karushev]

[Text] The Ryazan' Planning and Technological Institute (RPTI) has developed the technology of a mechanized process for producing printed-circuit boards, and the associated mechanized equipment. We know from the literature* that this process differs from those presently used to produce printed-circuit boards at the instrument making sector's plants in that it includes a number of operations performed on modular jet processing lines. The lines required for a given operation are assembled out of unified modules. The technical level of the unified modules developed in recent years has risen significantly, making it possible to achieve a 60-80 percent level of mechanization and automation.

Analysis of the technological processes associated with printed-circuit board production would show that its output variables, for example the quality of the printed boards, exhibit a complex dependence upon the parameters of the technological processes. In this case the determined factors define the significance and nature of changes in the mathematical expectation of a particular output variable, while factors which cannot be controlled and cannot be monitored define the significance and nature of random deviations of the latter from the mathematical expectation.

Inasmuch as there exist many unrevealed statistical mutual relationships between the parameters of the same operation and between parameters of different operations, and moreover because there are no series-produced sensors permitting measurement of concentrations in multi-ingredient solutions, or controllable valves resistant to chemicals, or automated Soviet production equipment, there are great difficulties in achieving full automation of the technological processes. This is why it would be expedient to automate individual steps of the production operations.

The RPTI has developed and introduced the first generation of an ASU TP [automated system for controlling technological processes] for printed-circuit board production.

*Truntsevskiy, V. R., "Technological Principles of Full Mechanization of Printed-Circuit Board Production," PRIBORY I SISTEMY UPRAVLENIYA, No 1, 1978.

It was created on the basis of the technological processes used in production of printed-circuit boards by a combined positive method in which the circuit pattern is applied photochemically. In terms of the type of production, these are referred to as continuous-discrete technological processes. Four operations (four steps) were selected for automation (in the first generation of the system): exposure, development, removal of the photoresist and etching. These operations have been studied the most deeply, and they yield relatively easily to automation. Parameters of the production process that can be monitored and controlled are: solution temperature and level; solution pressure in the line's jet systems; concentration of solution ingredients; operation time; number of boards processed.

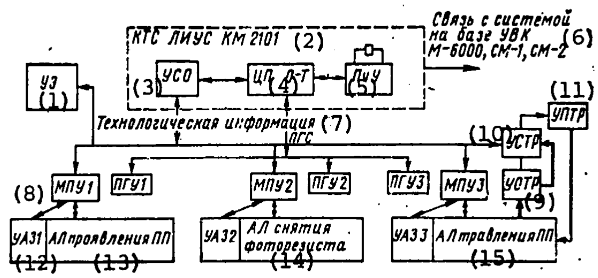
Effective operation of the system can be achieved by applying a number of systems engineering concepts. The complex of control algorithms includes special subroutines providing additional control over the system's preparation and preventing output of false control commands to the working organs. The system has a bilevel hierarchical structure (process control computer complex, local automated equipment) making it possible to switch to autonomous or manual control of the lines and units at any time.

The system's bilevel structure allows it to go on functioning when the equipment experiences a partial breakdown, when the process control computer complex experiences random failures and when the operator makes mistakes--that is, it ensures high viability for the system. When the upper level (the process control computer complex) fails, the system's operation in autonomous or manual control becomes less effective. However, the processes on the lines and units are not interrupted, and they may be continued without ruining the products or causing mishap. During the time of autonomous or manual control, the parts of the system that had broken down could be repaired and placed back into operation.

The ASU TP for printed-circuit board production is based on the LIUS KM2101 hardware complex. The figure below shows a simplified structural diagram of the system and its information pathways. The production equipment subjected to control includes: U898 exposure unit; A80 automated printed-circuit board development line; A81 automated photoresist removal line; A79 automated printed-circuit board etching line; equipment automatically loading the lines with boards to be processed; U908 etching solution preparation unit; U907 etching solution mixing unit; U906 etching solution purging unit.

The sensors and controls of the automated lines and units are connected to local control consoles and, by way of a switchboard, to the KM2101 complex's object linking unit. The system's technical resources also include the following, not shown in the figure: Automated line manual control consoles, automatic loading unit control consoles and power supply boxes.

The system is intended to operate in two modes--systemic and autonomous. Moreover the equipment can be operated in manual control mode . In systemic mode control is exercised on the basis of the time required for each operation depending on solution concentration, with the temperature, level and pressure maintained at set values. Operation time is set on the basis of an experimental characteristic depending on the surface area to be processed within a fixed volume of solution. Appropriately calculated control commands are fed continuously to the feed rate adjusting block; changing the rotation rate of the automated line's conveyer, the latter changes the operation time.



Simplified structural diagram of the ASU TP for printed-circuit board production: ПГУ-ПГУ 3--loudspeaker intercom unit; ПГС--production loudspeaker communication system.

Key:

1. Exposure unit
2. LIUS KM2101 hardware complex
3. Object linking unit
4. Operator-process engineer central console
5. Printing unit
6. Communication with system based on M-6000, SM-1, SM-2 process control computer complex
7. Technological information
8. Local control console
9. Etching solution purging unit
10. Etching solution mixing unit
11. Etching solution preparation unit
12. Automatic loading unit
13. Automatic printed-circuit board exposure line
14. Automatic photoresist removal line
15. Automatic printed-circuit board etching line

Boards to be processed are fed onto the automated line conveyers by the automatic loading unit from general-purpose cassettes, from which they are ejected one at a time. In systemic mode the automatic loading unit is controlled by the LIUS hardware complex. When the parameters of the technological processes occurring on the automated lines go beyond permissible limits, when mishaps arise or when the process falls out of synchrony, board loading onto the conveyer is automatically stopped. The problem of automating preparation of etching solution and its delivery to the automated etching line was partially solved in the first generation of the ASU TP for printed-circuit board production. Units U906-U908 were developed for this job. When the solution concentration attains a minimum permissible value, the KM2101 complex emits a command to replace the solution. The U906 unit pumps the solution from the production module into the U907 unit, and after the module is rinsed out, fresh solution is fed into it from the U908 unit.

Information on the progress of the technological processes is concentrated at the central console of the operator-process engineer in the form of light signals and digital displays. This central console consists of a UVKI1-3 unit from the KM2101 complex, somewhat modified. The printing unit periodically registers the technological parameters of all of the automated lines.

The organizational problems solved within this system include accounting for the quantity of finished products in the automated portions of the operations and preparation of information for the automated production control system.

In systemic mode, work is possible both with all automated lines and units simultaneously and with a part of them when some break down. In autonomous mode, the required conveyer speed is set manually by the operator on the basis of a table. The technological processes are monitored by way of light signals on local control consoles.

The economic impact of producing the system is about 160,000 rubles.

In the next phase of the development of this ASU TP for printed-circuit board production, the drilling and the chemical and galvanic copper-plating steps are to be automated.

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INTERNATIONAL SYSTEM OF SMALL COMPUTERS: BASIS FOR FURTHER DEVELOPMENT OF PROCESS CONTROL COMPUTER COMPLEXES FOR STATE SYSTEM OF INDUSTRIAL INSTRUMENTS AND AUTOMATION EQUIPMENT: SM-50 SERIES

Moscow PRIBORY I SISTEMY UPRAVLENIYA in Russian No 3, Mar 82 pp 25-26

[Article by candidates of technical sciences A. A. Myachev, S. S. Partsevskiy, S. N. Khrushchev and Ye. N. Filinov]

[Text] The State System of Industrial Instruments and Automation Equipment (GSP), which together with process control computer complexes (UVKs) of the SM EVM [International System of Small Computers] serves as the foundation for synthesizing ASU TPs [automated systems for controlling technological processes] of different classes and purposes, underwent development and further improvement in the 10th Five-Year Plan (1). The general trends in control automation within the principal industrial sectors (power engineering, metallurgy, machine building, chemistry, transportation) are typified by comparable outlays on acquisition of GSP and UVK instruments (correspondingly 30 and 20 percent of the total outlays on creation of ASU TPs (2)).

The integrated program for creation and development of SM EVM UVKs, in which enterprises of the Ministry of Instrument Making have participated together with the CEMA countries, promoted development of a new, functionally complete, complex system of computer resources with developed peripheral equipment and software (1). The program foresees the order of creating and developing SM EVM UVKs.

The first-generation SM EVM UVKs now being produced in large series use software compatible with that of former ASVT-M UVKs which the former have replaced. Naturally, this continuity will also be a feature of future SM EVM models. The volume of accumulated applications (user) software intended for more than 1,000 control systems is about 700 million commands (3).

Characterized by high productivity (140,000-320,000 operations per second in relation to their principal operations), expanded memories (up to 120,000 words) and a large nomenclature of peripheral units (PUs), object linking units (USOs) and adapters for GSP instruments, the first-generation models of SM EVM UVKs (from SM-1 to SM-4) are readily adaptable to the requirements of concrete users in the most important areas of application of SM EVM UVKs (4-6), among which we include, in addition to ASU TPs, scientific research and experiments.

The efforts to create resources for automating scientific research and experiments making use of a number of GSP measuring instruments make up one of the most important state programs (1). Measuring and computer complexes (IVKs) were created in the 10th Five-Year Plan and are now being produced within the framework of this program. These complexes have rightfully been isolated as an independent object of development and industrial production (5). IVKs have a unique feature: use of the most important state standard digital interfaces compatible with international standards, KAMAK and MEK 625-1 for programmed control of the work of measuring and controlling instruments.

The conception, plan and program of efforts to create the second-generation SM EVM (developed at the end of the 10th Five-Year Plan) are aimed at solving the following most important problems having a direct bearing on joint use of all GSP resources: satisfying the demand for and eliminating the scarcity of computer resources in the principal areas of their use; raising the technical-economic indicators of computer resources to the level of the best modern computers, expanding their functional possibilities and raising their flexibility and suitability for mass introduction into the national economy; raising the effectiveness of computer use; significantly enlarging the nomenclature of the available models of UVKs, peripheral equipment and software, with a consideration for their specialization within the hierarchy of computer resources (6).

The plan for development of the second-generation SM EVM foresees development of problem-oriented complexes (POKs) ensuring creation of highly effective automated control systems in selected areas of use (5). In contrast to the situation typical of standard and specialized UVKs, the basic applications software being developed and supplied to POKs will make it possible for the user to solve the most important problems with minimum reworking of the programs, which will significantly reduce the labor and material resources required to create local automated systems.

The objective of the integrated program is to develop the SM EVM in relation to the following main directions (7): Computer models of different classes and purposes; peripheral equipment, to include auxiliary memories with higher capacity and speed, and PUs based on new principles of operation; USOs consisting of functional units taking the form of integrated microcircuits intended for a number of applications (autonomous, dispersed and mixed); units for telemetric data processing systems; software, including packages of application programs, for the largest applications of the SM EVM; standard UVKs and IVKs serving as the basis for concrete user complexes, to include ones equipped with adapters for GSP equipment possessing standard interfaces (8,9).

All SM EVM models are being developed on the basis of large-scale integrated microcircuits assembled into microprocessors, circuits exhibiting higher integration, 8- and 6-bit microprocessors, memories characterized by significant volume and higher speed, and integrated microcircuits based on low-power TTLSh technology.

The principal classes of second-generation SM EVM models being developed in our country and their qualitative characteristics are shown in the table on the following page.

In terms of USOs, the program foresees a sharp increase in nomenclature, to include USOs based on large-scale integrated circuits--operation amplifiers, comparators and digital-analog converters.

Typical Features of the Structure and Use of Principal Classes of Second-Generation SM EVM Models

Microcomputers (SM-50)	System-Compatible Computers (SM-51)	High-Productivity Real Time Models (SM-52)	Multicomputer and Multiprocessor Models (SM-53)
Autonomous use; intelligent terminals; terminal stations; industrial controllers; instrumentation; modifications for specially complex operating conditions; subsystems realizing some functions of operating systems; 8- and 16-bit microcomputers of family SM-1800 using a Mul'tibus interface	Compatibility with UVK models from SM-1 to SM-4; technical-economic indicators two to four times better than those of UVK models SM-1 through SM-4; presence of special expander-processors--matrix, language, file, etc.; 16-bit, with flexible microprogram control; junior models in the class for terminal stations and dispersed control systems and computer networks based on senior models	Main memory with maximum volume; developed possibilities for reconfiguration and synthesis of multiprocessor UVKs; input-output channels represented by models in classes SM-50, SM-51; problem-oriented units in heirarchical integrated control systems	Use of system-compatible computer models and computer interfaces; programable peripheral input-output processors; 32-bit universal and specialized processors

In the area of software, there are plans for significantly raising the level of programming associated with systemic and application problems and for developing basic software to be used in the development of high-productivity systems, highly reliable territorially dispersed systems, local and dispersed timesharing information systems and so on.

Development and production of a number of standard multicomputer UVK configurations (to include two-computer) and a set of complexes with many general-purpose terminals will create a basis for synthesizing user complexes in the most important areas of joint use of SM EVM and GSP resources. Standard UVKs and IVKs will serve as the basis for synthesizing a large number of POKs of this class.

The plan for developing the SM EVM calls for creating POKs which, together with GSP resources, will provide for the needs of the areas that must be automated on priority (5): Continuous and continuous-discrete technological processes, mainly in rolling mill furnace shops and in control of the power-consuming steps of charge smelting, and charge calculation; the shops of enterprises involved in discrete production, and mainly control of groups of machine tools and conveyer systems, and coordination of control over the mechanical working section with control of the warehouse transportation system; industrial testing systems, including automated testing stands for technically complex articles (internal combustion engines, electric motors etc.); the multichannel measurement systems of analyzers determining product quality (for example measurement of microirregularity parameters during quality control of surfaces of processed parts), and of the composition and properties of substances (in particular, problems associated with selecting high-protein strains of cereal grains, operational control of the concentration of different ingredients in physics, biology and medicine); medical services to the public and the processing of instrumental examination data obtained from patients in therapeutic institutions; scientific experiments and research (laboratory experiments, automation of monitoring and measurements).

The principal research tasks associated with creating such POKs and IVKs are: Introducing, into measuring and control subsystems, microprocessor resources which would increase the proportion of data collection and preliminary processing equipment and procedures that would make use of rigid reloadable programs; developing efforts to create new resources and methods of metrological support to POKs and improving existing resources and methods; introducing microprocessor subsystems that would distribute control and data processing between the appropriate levels of a POK; introducing a standard analog interface compatible with digital interfaces.

By completing the work required by the SM EVM program in the basic areas of joint use of SM EVM and GSP resources, we will lay the basis for a transition to a higher qualitative level in terms of the most important user parameters. This will ensure a sharp shift in the level and effectiveness of solving different kinds of control problems, and in the final analysis it will produce a sizeable savings in labor, energy and materials.

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MICROCOMPUTER INTERFACE FOR PERIPHERAL EQUIPMENT

Moscow PRIBORY I SISTEMY UPRAVLENIYA in Russian No 3, Mar 82 pp 31-32

[Article by engineers P.A.Bondarenko, V. V. Koshtoyev and B. K. Kulidzhanov]

[Excerpt] Large-scale integrated microcircuits can be used to exchange information between peripheral equipment and microcomputers created on the basis of series K580 and K589 microprocessor units. Such microcircuits include the K580IK55 parallel programmable interface (PRI) and the K580IK51 series programmable interface (PSI). The former consists of three eight-bit universal linking buffers (ports), making data exchange possible between a central processor and peripheral units; the latter exchanges data with the peripheral units successively, bit by bit, and with the central processor in series and in parallel, byte by byte. This article describes a microcomputer interface based on series K580 microprocessors and having a minimum number of peripheral units--an SP-3 papertape reader, a PL-80 punch and a T-63 teleprinter.

The interface linking the reader and the punch with the microcomputer is diagramed in Figure 1 [figure not reproduced]. The microcomputer interacts by way of the interface with the reader and punch both in program mode via the PRI and in direct memory access mode in the event that there are no programs recorded in the main memory for exchange of data with the peripheral units. A special array counter is foreseen in the interface for interaction with the microcomputer in direct memory access mode. A number corresponding to the number of bytes being transmitted from the counter or printed out by the punch is fed into this counter from the console. Information is exchanged with the main circuit of the microcomputer in direct memory access mode through buffer registers--type K589IR12 integrated microciruits having terminals with three states.

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INTERFACE OF DRP-3M PLOTTER WITH NAIRI-2 DIGITAL COMPUTER

Moscow PRIBORY I SISTEMY UPRAVLENIYA in Russian No 3, Mar 82 pp 32-34

[Article by Candidate of Technical Sciences V. Ya. Durnovtsev and engineers L. V. Kulyasova, B. V. Brekhov and B. A. Andrianov]

[Excerpt] The Nairi-S, Nairi-2 and Nairi-K small digital computers have achieved universal recognition and broad use owing to the simplicity of their structure and their programming, the convenience of their maintenance and the possibility for their use by even nonprofessional programmers. However, they do have the significant shortcoming that the speed at which results are outputted is low (up to 8-10 symbols per second). A number of situations require a large volume of calculation results which are then used to represent the solution graphically, and in some tasks such as tabulating complex functions, analyzing transient processes in dynamic systems, solving ordinary differential equations and some others, graphs are the sole convenient way of displaying the results.

If we ignore the rather primitive attempts made with the "Nachertim" operator, series-produced Nairi digital computers do not allow for graphical representation of calculation results.

The complex for graphical representation of the calculation results of a digital computer described in this article includes a UP-7 digital-potential converter, a DRP-3M two-coordinate recording plotter and a Nairi-2 computer subjected to insignificant modifications making it possible to connect these devices and to ensure their joint operation. Computer calculation results represented by coordinate points (x_i, y_i) are converted in the UP-7 unit into analog values, which are used by the DRP-3M plotter to draw graphs taking the form of straight-line segments.

The interface was developed on the basis of the microprogram principle of controlling all operations, realized in the Nairi-2, which made it possible, after introducing additional microoperations and a "Key" operator, to expand the existing command "O" ("Access to Consul-254 Unit") to the command "Obrashcheniye"--"Access to Graph Plotting Unit" (see table [table not reproduced]).

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IRPS CONTROLLER FOR ELEKTRONIKA-60 MICROCOMPUTER

Moscow PRIBORY I SISTEMY UPRAVLENIYA in Russian No 3, Mar 82 pp 34-35

[Article by Candidate of Technical Sciences S. I. Yemets and engineers P. P. Kulikov, V. G. Makotchenko, A. A. Ovdiyenko and I. D. Petrenko]

[Excerpts] Multilevel information collection and processing systems and local automated control systems with remote terminals are often designed with a unified linking channel consisting of a small SM EVM [System of Small Computers] IRPS interface (interface for radial connection of units equipped for successive information transmission).* The IRPS controller described below can be used to synthesize such systems based on the Elektronika-60 microcomputer.

To provide for successive transmission of information, Elektronika-60 microcomputers are outfitted with a successive exchange device (UPO), over which the controller described here has a number of advantages. Owing to use of a universal synchronous-asynchronous transceiver (USAPP), designed as a large-scale integrated circuit, the K580IK51, the controller's flexibility is greater and its functional possibilities are broader: In particular, the rate of information transmission and reception between the microcomputer and peripheral devices may be program-varied within a range of 50-9,600 baud; the number of bits and information in the format of the transmitted code (5,6,7 or 8) and the number of "stop" bits (1,1.5 or 2) can be changed by means of program; parity (odd or even) transmission can be controlled; overall dimensions are twice less than those of a UPO; reliability is higher due to a smaller number of components.

A structural diagram of the RPS controller is shown in the accompanying figure [figure not reproduced].

The microcomputer linking buffer, made from K589AP26, K559IP1P and K559IP2P components, provides for controller addressing, two-way data exchange between the controller and the microcomputer channel, and reception and transmission of control signals. The transceiver links the two-way data channel of the (USAPP) with a multiplexer, and the linking buffer with the microcomputer. The direction of transmission is determined by the control signal produced by the control decoder. The transceiver is made out of K589AP16 components.

*Normative material, international classification of patents, computer technology 10-78. "Small computer system. Interface for radial connection of units equipped for successive information transmission, IRPS."

The communication buffer is designed for a peripheral unit connection circuit not less than 500 meters long. This link consists of two current circuits (for information reception and transmission) galvanically shared with the USAPP. The communication buffer transmitter is a current generator consisting of two KT361B transistors. The linking circuit is connected to its output. The receiver is based on a K293LP1B optron switch. State "1" in the circuits corresponds to a current of 15-25 mA, while state "0" corresponds to a current of 0-3 mA.

The controller is powered by two sources: +5 volts (consumed power not greater than 1 A) and +12 volts (consumed power not more than 0.15 A), its overall dimensions are 50×135×12 mm, and it is structurally compatible with the Elektronika-60 microcomputer.

The IRPS controller can be used in systems for successive information exchange containing standard units such as the 15 VVV-60/9600-003 UPO, contained within the Elektronika-60 microcomputer outfit, and among the modules of the SM-3 and SM-4 minicomputers, the SM-6002 and SM-8501.

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DESIGNS AND CALCULATION OF MICROCIRCUITS AND MICROCOMPONENTS OF COMPUTER EQUIPMENT

Moscow KONSTRUKTSII I RASCHET MIKROSKHEM I MIKROELEMENTOV EVA in Russian 1982 (signed to press 16 Oct 81) pp 2-4, 9, 13-14, 21-22, 42, 58, 59, 60, 62, 63, 64, 65, 68, 69-72, 199, 207, 252-255, 287-288

[Excerpts from book "Designs and Calculation of Microcircuits and Microcomponents of Computer Equipment" by Mikhail Fedorovich Ponomarev, Izdatel'stvo "Radio i svyaz'", 15,000 copies, 288 pages]

[Excerpts] ANNOTATION

The designs of hybrid and semiconductor integrated microcircuits, their components and fundamentals of their design--provision of functional accuracy, thermal modes, spurious communications and interference, reliability, technical and economic aspects of design and production and methods of design development--are considered. The book is intended for students of vuzes and may be useful to engineering and technical personnel of the electronics and radio engineering industry.

The reviewers are the Chair "Semiconductors and Dielectrics," Kiev Polytechnical Institute (Head of Chair Yu. M. Kalnibolotskiy) and Deputy Chief Engineer of NIITsEVT B. I. Yermolayev.

CONTENTS

PREFACE

Fourth-generation computer equipment is constructed on the basis of integrated microcircuits (IS) of medium and large level of integration that contain from tens to several thousand of the simplest logic elements. Both general-purpose integrated circuits produced in large quantities by specialized enterprises and designed for use in the most diverse computer equipment (EVA) and special-purpose integrated circuits produced in small series by computer equipment manufacturers and designed for use in specific developments are used in this equipment.

The need for special-purpose integrated circuits is determined by the special requirements on their electric parameters, characteristics and designs: for example, making specific functional conversions or processing information by a special program (semipermanent storage devices), provision of increased accuracy and stability (code-analog and analog-code converters) or increased power level (secondary power sources and control devices). Moreover, the required functional information conversions in special-purpose integrated circuits can be made on the basis of modern advances of optoelectronics, magnetic-electronics and cryoelectronics using original design-production solutions.

With regard to the restricted use of special-purpose integrated circuits and the rapidly changing nomenclature, organization of production of these microcircuits at specialized enterprises is unprofitable--they are developed and produced by computer equipment development enterprises. A leading role belongs to computer equipment technician-designers (specialty 0648) in solution of this problem. The curriculum "Designs and calculation of microcircuits and microcomponents of computer equipment" is provided by the academic program for training specialists in the field of integrated circuit design. According to a typical program of this discipline (index UMUT-6/907, 1976), the designs of the elements and components of integrated circuits, methods of calculating them and fundamentals of design and calculation of hybrid and semiconductor integrated circuits are considered in the proposed textbook.

With regard to the noted tendency of wider use of special-purpose semiconductor integrated circuits and large integrated circuits in computer equipment, the author devoted a sufficiently large amount of attention to problems of design of semiconductor integrated circuits. However, detailed methods of designing the active components of semiconductor integrated circuits are not presented in the book since special-purpose integrated circuits and large integrated circuits are usually developed with respect to semiconductor structures formed by standard production processes. In this case the designer mainly solves the topological problems since the electrophysical parameters and geometric dimensions of the layers in the cross-section of the semiconductor structure are known beforehand. The given electric parameters of the active and passive components are provided by correct selection of their topology and the corresponding geometric dimensions of the semiconductor domains.

Moreover, only the characteristic features of using a computer in design of microcircuits are considered in the textbook since the fundamentals of automated arrangement of components, routing of the interconnections and quality control of topology are studied in the preceding curriculum "Design automation."

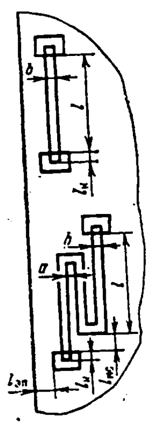
I would like to note in conclusion that the term "microcomponents of computer equipment" not usually employed for electronics is used in titling the academic discipline and accordingly the book. Microcomponents are understood here as suspended microminiature active and passive electronic radio components (transistors, resistors, capacitors, inductances and so on).

The author expresses gratitude to colleagues of the Chair of Design of Electronic Equipment, Taganrog Radio Engineering Institute, who assisted him in preparation of the manuscript, and also to reviewers, candidates of technical sciences B. I. Yermolyayev and Yu. D. Kobtsev for valuable comments that made it possible to improve the quality of the manuscript.

The integration exponent k, which is characterized by the number of elements and components contained in it N: $k = \lg N$, is introduced to evaluate the complexity of the integrated circuit. An integrated microcircuit of first degree of integration (IS1) contains up to 10 components, a circuit of second degree of integration (IS2) contains more than 10 up to 100 components, a circuit of third degree of integration (IS3) contains more than 100 up to 1,000 components, a circuit of fourth degree of integration contains more than 1,000 up to 10,000 components and a circuit of fifth degree of integration contains more than 10,000 up to 100,000 components. Integrated circuits containing more than 100 components on a crystal or more than 100 crystals with low level of integration located on the same substrate are called large integrated microcircuits (BIS).

The structure of the substrate material and its surface state have a significant effect on the structure of grown thin films and the characteristics of film elements. High surface roughness of the substrate reduces the reliability of thin-film resistors and capacitors since microroughnesses reduce the thickness of the resistive and dielectric films. A height of microroughnesses of approximately 25 nm is permissible with film thickness of approximately 100 nm. Accordingly, machining the substrate surface for thin-film microcircuits should correspond to surface roughness 14. Thick films have a thickness

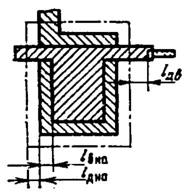
Table 1.1.1. Basic Design Requirements and Technological Restrictions

(1) Фрагмент топологии	(2) Требование	(3) Ограничение для данных технологических методов формирования контуров					
		М	Ф	МФ	ЭИ	ТА	ТП
1	2	3	4	5	6	7	8
	(4) Точность изготовления линейных размеров пленочных элементов и расстояний между ними $\delta(\Delta l)$, $\delta(\Delta b)$ и др. при расположении пленочных элементов в одном слое, мм	±0,01	±0,01	±0,01	±0,01	±0,01	±0,1
	(5) Минимально допустимый размер резистора, мм b	0,1	0,1	0,1	0,15	0,05	0,8
	l	0,3	0,1	0,3	0,3	0,1	0,8
	(6) Минимально допустимые расстояния между пленочными элементами, расположенными в одном слое, a, мм	0,3	0,1	0,3	0,1	0,05	0,3
	(7) Максимально допустимое соотношение размеров, l/b	10	100	30	100	100	—
	(8) Минимально допустимое расстояние между пленочными элементами, расположенными в разных слоях, $l_{мс}$, мм	0,2	0,1	0,2	0,1	0,1	0,4
	(9) Минимальное расстояние от пленочных элементов до края платы $l_{эп}$, мм	0,5	0,2	0,5	0,4	0,2	0,1
	Перекрытия для совмещения пленочных элементов, расположенных в разных слоях $l_{п}$, мм (10)	0,2	0,1	0,2	0,1	0,1	0,1

[Continued on following page]

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000500070016-2

Table 1.1.1 (Continued from preceding page).

1	2	3	4	5	6	7	8
	(11) Минимально допустимые расстояния, мм:						
	(12) между краем диэлектрика и краем нижней обкладки конденсатора $l_{дно}$	0,1	0,1	0,1	0,1	0,1	0,2
	(13) между краями верхней и нижней обкладок конденсатора $l_{вно}$	0,2	0,2	0,2	0,2	0,2	0,2
	(14) между краем диэлектрика и соединением вывода конденсатора с другим пленочным элементом $l_{дв}$	0,3	0,3	0,3	0,3	0,3	0,4
	(15) Минимальная площадь перекрытия обкладок конденсаторов, мм²	0,5×0,5	0,5×0,5	0,5×0,5	0,5×0,5	0,5×0,5	1,0×1,0
	(16) Минимально допустимая ширина проводников b, мм:						
	(17) тонкопленочных	0,1	0,05	0,1	0,1	0,05	—
	(18) толстопленочных при токе 6 А	—	—	—	—	—	1,00
	3 А	—	—	—	—	—	0,80
	2 А	—	—	—	—	—	0,60
	1 А	—	—	—	—	—	0,30
	0,3 А	—	—	—	—	—	0,15
	(19) Минимальные размеры контактных площадок (мм) для приварки проволочных проводников или проволочных выводов навесных элементов при диаметре проволоки, мкм:						
	25 (20) для одного проводника	0,15×0,1					—
	25 (21) для двух проводников	0,2×0,2					—
	50 для одного проводника	0,2×0,15					—
	50 для двух проводников	0,25×0,25					—
	100 для одного проводника	0,25×0,2					0,3×0,4
	100 для двух проводников	0,3×0,3					0,4×0,7

Note: M--mass; F--photolithographic; MF--mixed (mass + photolithographic); EI--electron-ion; TA--tantalum technology; TP--thick-film technology

Key:
1. Fragment of topology
2. Requirement
3. Restriction for given production methods of circuit formation

[Key continued on following page]

[Key continued from preceding page]:

4. Precision of manufacturing linear dimensions of film elements and distances between them $\delta(\Delta l)$, $\delta(\Delta b)$ and so on with arrangement of film elements in one layer, mm
5. Minimum permissible dimension of resistor, mm:
6. Minimum permissible distances between film elements arranged in same layer, a, mm
7. Maximum permissible ratio of dimensions, l/b
8. Minimum permissible distance between film elements arranged in different layers, l_{ms}, mm
9. Minimum distance from film elements to edge of card, l_{ep}, mm
10. Overlapping for combining film elements arranged in different layers, l_k, mm
11. Minimum permissible distances, mm
12. Between edge of dielectric and edge of lower plate of capacitor, l_{dno}
13. Between edges of upper and lower plates of capacitor, l_{vno}
14. Between edge of dielectric and connection of capacitor lead to other film element l_{dv}
15. Minimum overlap area of capacitor plates, mm^2
16. Minimum permissible width of conductors b, mm
17. Of thin-film
18. Of thick-film with current
19. Minimum dimensions of contact areas (mm) for soldering wire conductors or wire leads of suspended components with wire diameter, microns
20. For single conductor
21. For two conductors

of 10-50 microns; therefore, the substrate for thick-film integrated circuits can have microroughnesses up to 1-2 microns, which corresponds to surface roughness of 8-10. The height of the microroughnesses should be 50-200 nm to ensure good adhesion of the paste to the substrate.

The overall dimensions of substrates are standardized. Several plates of film microcircuits are usually manufactured by the group method on a standard substrate. Nonwaste division of a standard substrate into 2, 3, 4, 6, 8, 12 or more parts yields a normalized series of standard card dimensions. The standard dimensions recommended for use of cards are given in Table 2.2.1. Card dimensions Nos 3-10 correspond to the fit locations of standard housings. Cards with the remaining numbers are used in microassemblies. The substrate thickness comprises 0.35-0.6 mm.

Types of housings. According to GOST 17467-72 "Integrated microcircuits. Housings," the housings of domestic microcircuits are divided into four types. The basis of classification are the shape of the housing and the arrangement of the leads with respect to the body (an article without leads) of the housing. The main shapes of housings and the arrangement of their leads are shown in Figure 2.4.1: type 1 is a rectangular housing and the leads are arranged perpendicular to the base within the body of the housing (a), type 2 is a rectangular housing and the leads are arranged perpendicular to the base within the body of the housing (b), type 3 is a round housing and the leads are

Table 1.1.2. Basic Parameters of Thin-Film Resistor Materials

(1) Материал для напыления резистивной пленки	(2) Материал контактных площадок	(3) Удельное поверхностное сопротивление резистивной пленки $\rho_\square$, Ом/□	(4) Диапазон номинальных значений сопротивлений, Ом	(5) Максимально допустимая удельная мощность рассеяния P_0, Вт/см²	(6) Температурный коэффициент сопротивления (ТКС), °С⁻¹, в интервале температур от −60 до +125° С
Нихром, проволока Х20Н80 Ø0,3...0,8 мм (ГОСТ 12766—67) (7)	Медь (8)	300	50...30 000	—	$1\cdot10^{-4}$
Нихром, проволока (ГОСТ 8803—58) (9)	Золото с подслоем хрома (10)	10	1...10 000	—	$-2{,}25\cdot10^{-4}$
		50	5...50 000		
Сплав МЛТ-3М (6КО.028.005 ТУ) (11)	Медь с подслоем ванадия (луженая) (12) Медь с подслоем нихрома (защищенная никелем) (13)	500	50...50 000	2	$2\cdot10^{-4}$
Хром (ГОСТ 5905—67) (14)	Медь (луженая) (15)	500	50...30 000	1	$0{,}6\cdot10^{-4}$
Кермет К-50С (ЕТО.021.013.ТУ) (16)	Золото с подслоем хрома (нихрома) (17)	3000 5000 10 000	1000...10 000 500...200 000 1000...10 000 000	2	$3\cdot10^{-4}$ $-4\cdot10^{-4}$ $-5\cdot10^{-4}$
Тантал ТВЧ: лента толщиной 0,3...3 мм (РЭТУ 1244—67) (18)	Алюминий с подслоем ванадия (19)	20...100	100...10 000	3	$-2\cdot10^{-4}$
	Медь с подслоем нихрома (20)	100	50...100 000	—	—
	Тантал (21)	10	10...15 000	—	—
Сплав РС-3001, (ЕТО.021.019 ТУ) (22)	Золото с подслоем хрома (нихрома) (17)	1000 2000	100...50 000 200...100 000	2	$-0{,}2\cdot10^{-4}$
Сплав РС-3710 (ЕТО.021.034 ТУ) (23)		3000	1000...200 000	2	$-3\cdot10^{-4}$

Key:
1. Material for deposition of resistive film
2. Material of contact surfaces
3. Specific surface resistance of resistive film $\rho_\square$, ohms/□
4. Range of nominal values of resistors, ohms
5. Maximum permissible specific dissipation P_0, W/cm²

[Key continued on following page

[Key continued from preceding page]:

6. Temperature resistance coefficient (TKS), °C^{-1} in temperature range from -60 to +125°C
7. Nichrome, Kh20N80 wire 0.3-0.8 mm in diameter (GOST 12766-67)
8. Copper
9. Nichrome wire (GOST 8803-58)
10. Gold with chrome sublayer
11. MLT-3M alloy (bKO.028.005TU)
12. Copper with vanadium (tinned) sublayer
13. Copper with nichrome sublayer (protected by nickel)
14. Chrome (GOST 5905-67)
15. Copper (tinned)
16. K-50S cermet (YeTO.021.013.TU)
17. Gold with chrome (nichrome) sublayer
18. TVCh tantalum; film 0.3-3 mm thick (RETU 1244-67)
19. Aluminum with vanadium sublayer
20. Copper with nichrome sublayer
21. Tantalum
22. RS-3001 alloy (YeTO.021.019.TU)
23. RS-3710 alloy (YeTO.021.034.TU)

Table 1.1.3. Electric Parameters of Resistive Thick Films

Mark of Initial Paste	Specific Surface Resistance $\rho_\square$, ohms/$\square$	Noise Coefficient K_{sh} (f = 0.6-1.6 kHz, P_0 = 0.5 W/cm^2)
Pr-5	5	0.5
Pr-20	20	0.5
Pr-100	100	0.5
Pr-500	500	1
Pr-1K	1,000	5
Pr-3K	3,000	5
Pr-6K	6,000	5
Pr-20K	20,000	10
Pr-50K	50,000	10
Pr-100K	100,000	10

arranged perpendicular to the base within the body of the housing (c) and type 4 is a rectangular housing with planar leads (d).

GOST 17467-72 establishes the overall dimensions and connecting dimensions and the notations of housings. The distances between the centers of leads of the first and second type of housings is 2.5 mm, that of the third type is at an angle of 30 and 45°, that of the fourth type is 1.25 mm and the distance in BGIS multilead housings is 0.625 mm. In the latter case four-row shaping of leads is accomplished. The distances between the centers of the contact surfaces of a printed-circuit card should be 1.25 mm. The notation of the housing design consists of the standard dimension code of the housing, a

Table 1.2.1. Main Characteristics of Thin-Film Capacitor Dielectric Materials

(1) Материал для напыления диэлектрика	(2) Материал для напыления обкладок	(3) Удельное поверхностное сопротивление пленки обкладок $\rho_{\square}$, Ом/□	(4) Удельная емкость C_0, пФ/см²	(5) Рабочее напряжение $U_{раб}$, В	(6) Диэлектрическая проницаемость $\varepsilon_д$ на частоте 1 кГц	(7) Тангенс угла диэлектрических потерь tgδ на частоте 1 кГц	(8) Электрическая прочность $E_{проб}$, В/см	(9) Температурный коэффициент емкости (ТКЕ), °С⁻¹ в интервале температур −60...+125°С
Моноокись кремния (ЕК0.028.004 ТУ) (10)	(14) Алюминий А99 (ГОСТ 11069—64)	0,2	5 000 10 000	60 30	5,0...6,0	0,01...0,02	(2...3)·10⁶	2·10⁻⁴
Моноокись германия (ЕТ0.021.014 ТУ) (11)			5 000 10 000 15 000	10 7 5	11...12	0,005...0,007	1·10⁶	3·10⁻⁴
Боросиликатное стекло (ЕТ0.035.015 ТУ) (12)			2 500 5 000 10 000 15 000	24 15 10 8	4	0,001...0,0015	(3...4)·10⁶	0,35·10⁻⁴ для температур 25...155°С (15)
Стекло электровакуумное С41—1 (НП0.027.600) (13)			15 000 20 000 30 000 40 000	12,6 10...12,6 6,3...10 6,3	5,2	0,002...0,003	(3...4)·10⁶	(0,5...1,0)·10⁻⁴ для −60...+25°С (1,5...1,8)·10⁻⁴ для +25...+125°С (16)
Пятиокись тантала (электролитическое анодирование) (17)	(18) Тантал ТВЧ (нижняя обкладка)	1...10	60 000 100 000	15 10	—	—	—	—
	(19) Алюминий А99 (ГОСТ 11069—64) с подслоем ванадия (верхняя обкладка)	0,2	200 000	3	23	0,02	2·10⁶	4·10⁻⁴

Key:
1. Materials for dielectric deposition
2. Material for plate deposition
3. Specific surface resistance of plate film $\rho_{\square}$, ohms/□
4. Specific capacitance C_0, pF/cm^2
5. Working voltage U_{rab}, V

[Continued on following page]

[Key continued from preceding page]

6. Permittivity ε_d at frequency of 1 kHz
7. Tangent of dielectric loss angle tgδ at frequency of 1 kHz
8. Electric strength E_{prob}, V/cm
9. Temperature coefficient of capacitance (TKE), °C^{-1} in temperature range -60 to +125°C
10. Silicon monoxide (YeK0.028.004 TU)
11. Germanium monoxide (YeT0.021.014 TU)
12. Borosilicate glass (YeT0.035.015 TU)
13. S41-1 electrovacuum glass (NP0.027.600)
14. A99 aluminum (GOST 11069-64)
15. For temperatures
16. For
17. Tantalum pentoxide (electrolytic anodization)
18. TVCh tantalum (lower plate)
19. A99 aluminum (GOST 11069-64) with vanadium sublayer (upper plate)

Table 2.2.1. Recommended Card Sizes

№ п/п (1)	Ширина, мм (2)		(5) Длина, мм	
	номинальное значение (3)	отклонение (4)	номинальное значение	отклонение
1	96		120	
2	60	— 0,3	96	
3	48		60	— 0,3
4	30		48	
5	24	— 0,2	30	
6	20		24	— 0,2
7	16		20	
8	12		16	
9	10		16	
10	10	— 0,1	12	— 0,1
11	5		6	
12	2,5		4	
13	16		60	— 0,3
14	32	— 0,2	60	
15	8	— 0,1	15	— 0,1
16	8		10	
17	24	— 0,2	60	
18	15	— 0,1	48	— 0,3
19	20	— 0,2	48	

Key:
1. Number of item
2. Width, mm
3. Nominal value
4. Deviation
5. Length, mm

Table 2.2.2. Electrophysical Parameters of Substrate Materials

(1) Параметр	(2) Стекло		(3) Ситалл СТ50-1	(4) Плавленый кварц	(5) Керамика			
	С41-1	С48-3			22ХС (96% Al_2O_3)	(6) Поликор	Глазурованная (7)	99,5% BeO
Класс чистоты обработки поверхности (8)	14	14	13 — 14	14	12	12...14	14	Высота (9) микронеровностей до 0,45 мкм
ТКЛР, $°C^{-1}$ (в интервале температур, °C) (10)	$(41\pm2)\,10^{-7}$ (20...300)	$(48\pm2)\,10^{-7}$ (20...300)	$(50\pm2)\,10^{-7}$ (20...300)	$55\cdot10^{-7}$ —	$(60\pm5)\,10^{-7}$ (20...200); $(20\pm5)\,10^{-7}$ (20...500); $(75\pm5)\,10^{-7}$ (20...900)	$(70...75)10^{-7}$ (20...800)	$(73...78)10^{-7}$ (до 400)	$70\cdot10^{-7}$
Теплопроводность, (11) Вт/(м·°C)	1	1,5	1,5	7...15	10	30...45	1,2...1,7	210
Температура размягчения, °C (12)	—	750	620	1[illegible]00	1500	—	1900	1000
Диэлектрическая проницаемость при $f=10^6$ Гц и $T=+20°C$ (13)	7,5	3,2...8	5...8,5	3,8	10,3	10,5	13...16	6,4...9,5
(14) Тангенс угла диэлектрических потерь при $f=10^6$ Гц и $T=+20°C$	$20\cdot10^{-4}$	$15\cdot10^{-4}$	$20\cdot10^{-4}$	—	$6\cdot10^{-4}$	$18\cdot10^{-4}$	$18\cdot10^{-4}$	$16\cdot10^{-4}$
Объемное сопротивление, (15) Ом·см, при 25°C	10^{17}	10^{14}	—	10^{18}	—	—	—	10^{14}
Электрическая прочность, (16) кВ/мм	40	40	—	—	50	—	50	20

Key:
1. Parameter
2. Glass
3. ST50-1 Sitall
4. Fused quartz
5. Ceramics
6. Polykor
7. Glazed
8. Surface roughness of machining
9. Height of microroughnesses up to 0.45 micron
10. Linear temperature expansion coefficient, $°C^{-1}$ (in temperature range, °C)

[Key continued on following page]

[Key continued from preceding page]:

11. Heat conduction, W/(m·°C)
12. Softening temperature, °C
13. Permittivity at f = 10^6 Hz and T = +20°C
14. Tangent of dielectric loss angle at f = 10^6 Hz and T = +20°C
15. Volume resistance, ohms·cm, at 25°C
16. Electric strength, kV/mm

Table 2.3.1. Parameters of Multicomponent Systems of Commutation Conductors and Contact Surfaces

Material	Thickness of Layer, nm	Specific Surface Resistance $\rho_\square$, ohms/□	Recommended Method of Contact of External Leads
Sublayer--Kh20N80 nichrome (GOST 2238-58)	10-30		
Layer--Z1 999.9 gold (GOST 7222-54)	600-800	0.03-0.04	Soldering, welding
Sublayer--Kh20N80 nichrome (GOST 2238-58)	10-30		
Layer--vacuum melting of MV copper (MRTU 14-14-42-65)	600-800	0.02-0.04	Welding
Coating--nickel (MRTU 14-14-42-65)	80-120		
Sublayer--Kh20N80 nichrome (GOST 2238-58)	10-30		
Layer--vacuum melting of MV copper (MRTU 14-14-42-65)	600-800	0.02-0.04	Soldering, welding
Coating--Z1 999.9 gold (GOST 7222-54)	50-60		
Sublayer--Kh20N80 nichrome (GOST 2238-58)	40-50		
Layer--A99 aluminum (GOST 11069-64)	250-350	0.1 -0.2	Soldering
Coating--nickel (MRTU 14-14-46-65)	50		

number that indicates the number of leads and the modification number. The standard dimension code of the housing consists of notation of the type of housing (1, 2, 3 or 4) and a two-digit number (from 01 to 99) that denotes the standard dimension number. For example, housing 201.14-2 is a rectangular housing of type 2, standard dimension 01 with 14 leads, second modification.

Housing designs. Based on the characteristic features of design-production version, housings can be divided into several types: glass, ceramic, plastic,

Table 2.3.2. Main Parameters of Thick-Film Conductors

Parameter	Paste PP-1	PP-2	PP-3	PP-4
Film thickness d, microns	10-20	15-20	15-25	15-25
Specific surface resistance $\rho_\square$, ohms/□	0.05	0.05	0.05	0.05
Minimum distance between conducting elements in one layer, mm	0.2	0.2	0.05	0.1
Minimum dimensions of conductors, mm	0.25	0.25	0.15	0.2
Maximum precision of manufacturing films of components, mm	±0.1	±0.1	±0.05	±0.1

Table 2.3.3. Electrophysical Parameters of Materials of Insulating Layers

Parameter	Mark of Cement STs-273	STs-45
Melting point, °C	350	600
Solidification temperature, °C	750	700
Linear expansion coefficient, $°C^{-1}$	$5.2 \cdot 10^{-6}$	$3 \cdot 10^{-6}$
Permittivity	17	7-8
Tangent of dielectric loss angle	$2.5 \cdot 10^{-3}$	$3 \cdot 10^{-3}$
Specific volume resistance at 20°C, ohms·cm	10^{13}	10^{13}

Table 2.3.4. Maximum and Recommended Values of Design-Production Parameters of Thick-Film Switching Parts

Parameter	Recommended	Maximum
Number of layers of conductor switching	2	5
Distance between centers (spacing), mm:		
of interlayer junctions	1	0.6
of parallel conductors	0.5	0.3
Width of conductors (minimum), mm	0.25	0.15
Specific resistance of conductors, ohms/□:		
of internal layers	0.03	--
of outer layer (after tinning)	0.005	--

metal-glass, cermet, metal-polymer, glass-ceramic and so on. The designs of the most widely used housings are shown in Figures 2.4.2-2.4.4. Metal-glass housings 151.14-1, 151.15-2, 151.15-3, 155.15-4 and 155.36-1 (Figure 2.4.2) are widely used in hybrid integrated circuits. A total of 15 pin type leads, one of which is connected to the metal shell to accomplish electrostatic shielding, is used in housings 151.15-2, 151.15-3 and 151.15-4.

Table 2.3.5. Parameters of Layers of Thin-Film Switching Card

Layer	Material	Thickness, microns	Surface Resistivity, p/ohms	Permittivity, ε_d	Specific Capacitance at Intersection Domains C_0, pF/cm^2
First metal coating	Al	5	0.005	--	--
Two-layer dielectric	SiO	0.5	--	2-8	10
	PAK-1	3.5	--	3.4-4.5	
Second metal coating	Al	3.5	0.009	--	--

Table 2.4.1. Parameters of Materials Used to Manufacture Housings

Материал (1)	(2) Состав, %	(3) ТКЛР, °С$^{-1}$	Коэффициент (4) теплопроводности, Вт/(м·°С)
Алюминиевая керамика (5)	94...96 Al_2O_3, 6...4 MgO и (6) SiO_2	(6,4...7,9) 10^{-6}	19,6
Бериллиевая керамика (7)	97...99 BeO	7,0·10^{-6}	208
Боросиликатное стекло (8)	—	4,6·10^{-6}	1,1
Припайное стекло (9)	58PbO, 12Ba_2O_3, 20SiO_2, 8ZnO, 2 — прочие окислы (10)	(4,0...12,0) 10^{-6}	—
Ковар (11)	18Co, 28Ni, 54Fe	(4,7...5,5) 10^{-6}	16,7
Керамвар (12)	25Co, 27Ni, 48Fe	8,1·10^{-6}	—
Припой (13)	61Sn, 39Pb	21,5·10^{-6}	—
Пластмассы (14)	—	(20...200) 10^{-6}	0,3...2,0

Key:
1. Material
2. Composition, percent
3. Linear temperature expansion coefficient, °C^{-1}
4. Heat conductivity coefficient, W/(m·°C)
5. Aluminum ceramic
6. And
7. Beryllium ceramic
8. Borosilicate glass
9. Soldered glass
10. Miscellaneous oxides
11. Kovar
12. Keramvar
13. Solder
14. Plastics

Multilead ceramic housings 421.48-1 and 421.50-1 (Figure 2.4.3) are used in large hybrid integrated circuits. The ceramic base and cover of the housing simultaneously perform of the role of multilayer thick-film switching cards. Planar leads are arranged along the long sides with spacing of 1.25 mm. External intercard installation connectors are arranged along the narrow sides.

An example of a design of a metal-polymer housing is shown in Figure 2.4.4. A ceramic card (1) with pin-type leads (2) is placed inside a metal cap (3). The end cavity of the design is filled with a compound (4). The design does not provide quality protection of the microcircuit components under increased moisture conditions.

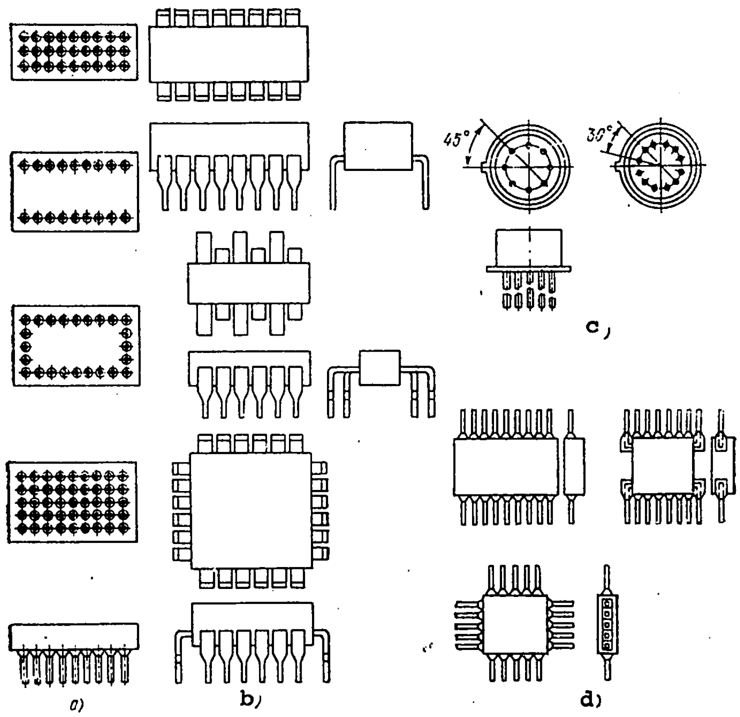


Figure 2.4.1. Types of Microcircuit Housings

The leads of the housings are numbered. The numbers of the leads are placed on the schematic diagram of the microcircuit and on the corresponding contact surfaces of the card. Special marks are made to determine the position of the first lead on the housing: a recess on the lead, asymmetrical arrangement of one of the leads, a notch or point on the housing surface and so on. The numbering proceeds clockwise if one looks at the housing from the direction of the leads.

The accuracy of reproducing the resistance of a semiconductor resistor is determined by the following factors: the precision of manufacture of the phototemplate and photoresistive mask, the precision of the etching process in which the opening in the protective oxide layer with given length to width ratio is formed and the precision of proportioning and distribution of the impurity atoms during alloying of the semiconductor by diffusion or ion implantation.

The effect of production operations on the accuracy of reproducing the resistance and the ratio of the resistance of diffusion resistors is illustrated by the data of Table 4.8.1. It is obvious from the data of the table that the main error is introduced at the impurity diffusion stage since it is rather difficult to control the amount of introduced impurity and the depth of

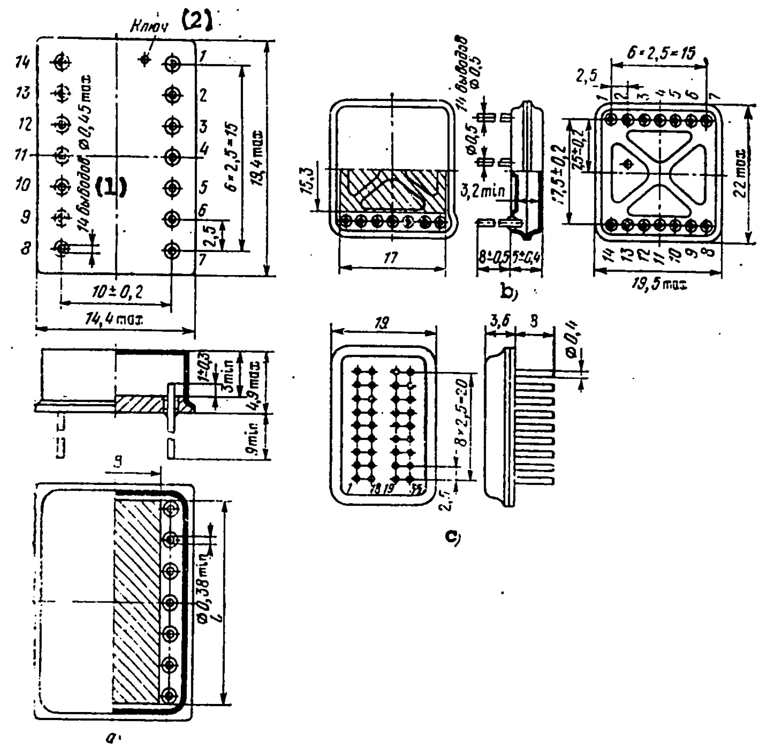


Figure 2.4.2. Designs of Metal-Glass Housings 151.14-1 (a), 151.15-3 (b) and 151.36-1 (c)

Key:
1. Leads
2. Legend

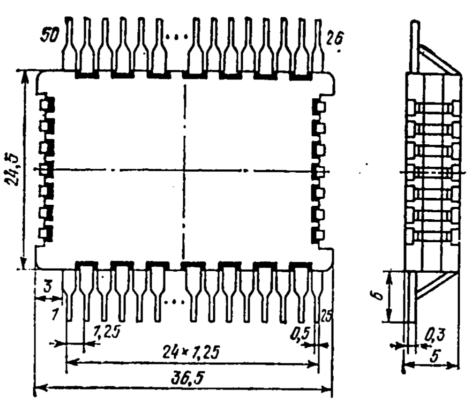


Figure 2.4.3. Design of Ceramic Housing 421.50-1

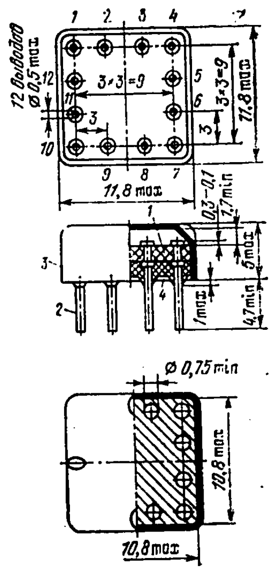


Figure 2.4.4. Designs of Metal-Polymer Housing: 1--ceramic card; 2--pin-type leads; 3--metal cover; 4--compound

Table 4.8.1. Effect of Production Operations on Precision of Diffusion Resistors

	$\frac{\Delta R}{R}$, %	$\Delta\left(\frac{R_1}{R_2}\right) / \frac{R_1}{R_2}$, %
Manufacture of phototemplate and masking	1	1
Etching during manufacture of protective mask	2	1
Diffusion of impurities	7	1
Entire production process	$\pm$10	$\pm$3

deposition of the p-n junction. The ratio of the resistance of two resistors is reproduced with sufficiently high accuracy since the resistive layers are formed simultaneously. This feature is used extensively in design of the circuitry of a microcircuit. Circuit developers attempt to perform it so that the output parameter of the microcircuit is determined by the ratio of the resistances of the diffusion resistors.

Rather precise control of the beam intensity and the dose of introduced ions is possible with ion implantation. The resistance of the resistor formed by the ion implanatation method can be reproduced with accuracy of not more than $\pm$ 5 percent.

Table 4.9.1. Parameters of Thin-Film Capacitors with Metal-Dielectric-Semiconductor Structure

Parameters			
Specific capacitance, pF/mm^2	400-600		800-1,600
Relative permittivity of dielectric	2.7-4.2		3.5-9
Breakdown voltage U_{prob}, V		50	
Variation of capacitances, percent		±20	
Variation of capacitance ratio, percent		± 3	
Temperature coefficient, $°C^{-1}$	$+15 \cdot 10^{-6}$		$+(4-10)10^{-6}$
Q-factor (at 10 MHz)	25-80		20-100

Glass, metal-glass, cermet and plastic housings are used to seal the crystals of semiconductor integrated circuits. The designs of flat housings 401.14-1 and 401.14-2 are shown in Figure 5.6.4. Housing 401.14-1 has a glass base with 14 flat planar leads arranged along the long sides with spacing of 1.25 mm. The metal cover of the housing is soldered to the metal-coated surface of the base. Metal-glass housing 401.14-2 has a metal bottom of the base, which permits a significant reduction of the thermal resistance of the housing (see Figure 5.6.3). Flat cermet housings with 24 and 48 leads are used to seal the crystals of large integrated circuits. Examples of the design of cermet housings are shown in Figure 5.6.5. The leads on the body of the housing are formed by the thin-film method (melting the metal into the ceramic. Airtightness of the housing in the regions of the leads is provided by the use of a multilayer ceramic. The crystal of a large integrated circuit is soldered to the metal base of the housing to reduce thermal resistance.

Rectangular plastic housings are used extensively in integrated circuits and large integrated circuits of personal and stationary calculators operating under normal conditions. The contact surfaces of the crystal in the design of plastic housing 201.14-1 (Figure 5.6.6) are connected to the leads of the housing by wire jumpers. Crystals with spider leads are used in automated assembly. Plastic housings are characterized by low cost and the possibility of automated manufacture. The disadvantages are the inadequate moisture resistance, limited operating temperature range (-10 to +70°C) and rather high thermal resistance ($R_{tk} \approx 100°C/W$). The latter circumstance limits the use of plastic housings only in comparatively low-power integrated circuits and large integrated circuits ($P \leq 250$ mW).

Round metal-glass housings 301.8-2 and 301.12-1 have 8 or 12 pin-type leads. The design of housing 301.8-2 (Figure 5.6.7) is characterized by a good seal and protection of the crystal against electromagnetic effects. However, this housing design does not permit good thermal contact with heat dissipation and high configuration density of computer equipment units.

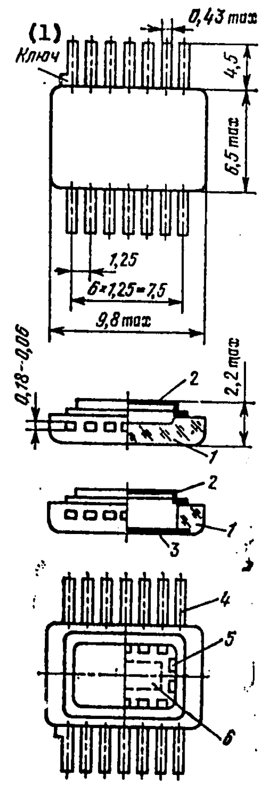


Figure 5.6.4. Designs of Flat Glass (401.14-1) and Metal-Glass (401.14-2) Housings with 14 Leads: 1--glass base; 2--metal cover; 3--metal bottom; 4--planar leads; 5--contacts for connection of wire leads of crystal; 6--recess for crystal

Key:
1. Legend

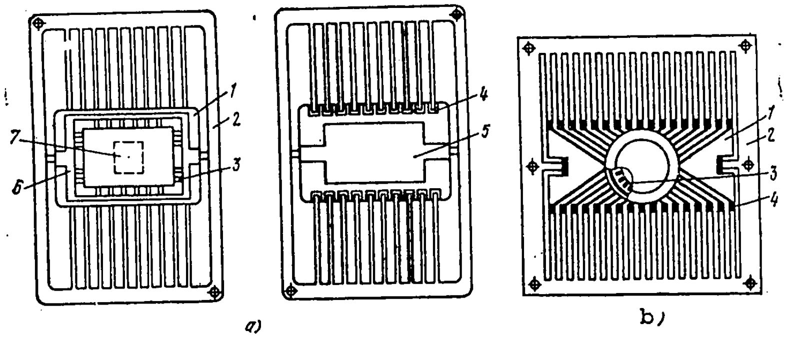


Figure 5.6.5. Designs of Flat Rectangular (a) and Round (b) Cermet Housings with 24 Leads: 1--ceramic body of housing; 2--lead frame; 3--internal contact surfaces; 4--metal-coated leads of housing; 5--metal base of housing (bottom); 6--metal-coating molding for sealing; 7--recess for crystal

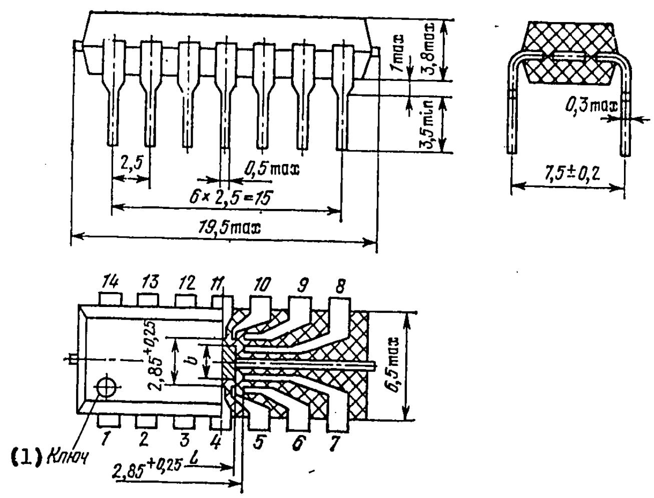


Figure 5.6.6. Designs of Plastic Housing 201.14-1

Key:
1. Legend

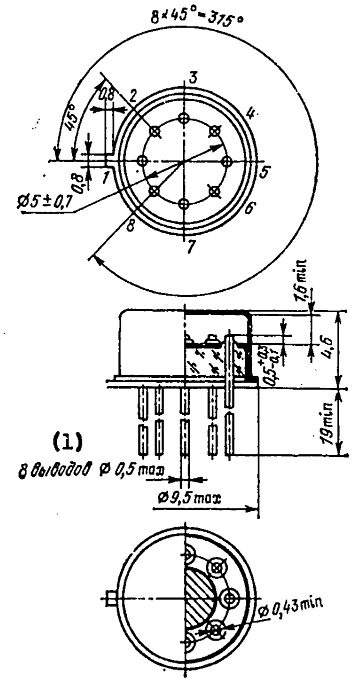


Figure 5.6.7. Design of Round Metal-Glass Housing 301.8-2

Key:
1. Leads

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HYBRIDS

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TECHNOLOGY, RELIABILITY AND AUTOMATION OF PRODUCTION OF LARGE-SCALE HYBRID INTEGRATED CIRCUITS AND MICROASSEMBLIES

Moscow TEKHNOLOGIYA, NADEZHNOST' I AVTOMATIZATSIYA PROIZVODSTVA BGIS I MIKROSBOROK in Russian 1981 (signed to press 20 Jul 81) pp 1-4, 245-267, 314-346, 350-351

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[Text] This book has been approved by the USSR Ministry of Higher and Secondary Specialized Education as a textbook for VUZ students specializing in "Design and Production of Radio Equipment" and "Design and Production of Electronic Computer Equipment."

ANNOTATION

The authors discuss methods for designing and insuring the quality of microcircuits and methods for and special features of calculating the reliability, functional accuracy and technological reproducibility of BGIS's [large-scale hybrid integrated circuit] and microassemblies. They explain the basic technological processes involved in the production of BGIS's and microassemblies and discuss systems and methods for automating the designing of BGIS's and microassemblies and equipment based on them, as well as methods for modeling and controlling the technological processes involved in the production of BGIS's and microassemblies.

This book is intended for VUZ students and specialists engaged in the design and production of radioelectronic and electronic computer equipment.

FOREWORD

The present period of development of radio equipment building is characterized by a universal transition from equipment based on discrete elements to microelectronic equipment (MEA) based on integrated circuits (IS). In order to produce and develop

MEA, it is necessary to know the physics of operation, failure mechanisms and qualitative characteristic formation factors of MEA elements.

In high-quality MEA and vehicle-borne equipment with improved size and weight characteristics, the basic design elements are BGIS's and microassemblies based on housingless, semiconducting IS's. The qualitative characteristics and reliability of MEA are determined by the qualitative characteristics and reliability of the BGIS's and microassemblies. Therefore, an engineer engaged in designing and producing MEA must known the technologcial design features of BGIS's and microassemblies and their interrelationship with the functional parameters and master the methods for calculating the quality characteristics of IS's, BGIS's and microassemblies and the methods for their technological support and automated design and production.

This book is devoted to these questions. In it the following subjects are discussed:
the basic technological operations that form and determine the qualitative characteristics of thin-film BGIS's and an analysis of their technical capabilities;
methods for and features of the calculation of the reliability, functional accuracy, technological reproducibility and other qualitative characteristics of BGIS's and microassemblies;
the state of and prospects for the automation of the designing, technological preparation for production and manufacturing of BGIS's and microassemblies, as well as controlling their quality during the production process.

The explanation of the material and the engineering calculation methods is illustrated with process diagrams, algorithm flowcharts and examples of designs and calculations.

The book is intended to be used as a textbook for VUZ students in specialties 0705 and 0648, the design and production of REA [radioelectronic equipment] and EVA [electronic computer equipment]. It can also be useful to REA designers and process engineers specializing in the area of designing and producing microelectronic equipment.

Materials from the domestic and foreign press, as well as the authors' works and lectures, are used in this book.

The Introduction and Chapters 1, 5, 6, 7 and 8 were written by A.V. Fomin, Chapters 2-4 by Yu.I. Bochenkov and Chapters 9-11 and the Appendices by V.A. Sorokopud.

The authors wish to express their sincere gratitude and thanks to Professors Yu.P. Yermolayev and L.A. Koledov, doctors of technical sciences, and the collectives of the Department of Microelectronics, Moscow Institute of Electronic Technology, and the Department of Microelectronics and REA Design, Kazan' Aviation Institute, for the valuable comments and advice offered during the review of the book that made it possible to improve its contents.

CHAPTER 9. AUTOMATING THE DESIGNING OF BGIS'S AND MICROASSEMBLIES

SECTION 9.3. EQUIPMENT FOR AUTOMATING THE DESIGNING AND TECHNOLOGICAL PREPARATION FOR PRODUCTION OF BGIS'S AND MICROASSEMBLIES

Systems for the automated designing and technological preparation for production of BGIS's are based on modern computer facilities, most frequently on multicomputer complexes with a centralized structure. The central computer usually solves problems on the REA cell, subblock and block level, while the peripheral ones solve the problems involved in the designing and technological preparation for production of BGIS's and wiring boards.

Since the makeup of a SAPR's [automated design system] determines, to some extent, the other equipment in the system, let us first discuss the hardware (Figure 9.3).

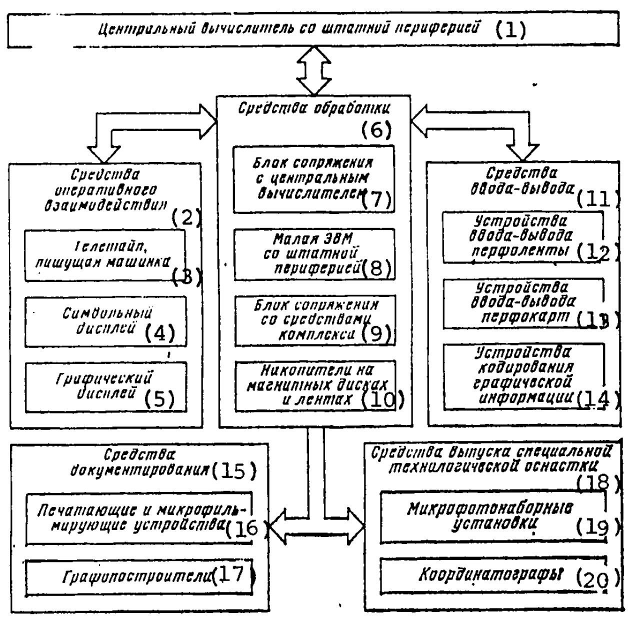

Figure 9.3. Hardware of system for automated designing and technological preparation for production of BGIS's.

Key:

1. Central computer with standard peripheral gear
2. Operation interaction facilities
3. Teletype, printer
4. Character display
5. Graphic display
6. Processing facilities
7. Unit for coupling with central computer
8. Small computer with standard peripheral gear
9. Unit for coupling with other equipment in complex
10. Magnetic disk and tape storage units
11. Input-output facilities
12. Punched tape input-output equipment
13. Punched card input-output equipment
14. Graphic information encoding equipment
15. Documentation facilities
16. Printing and microfilming equipment
17. Plotter
18. Facilities for output via special equipment accessories
19. Microphone installations
20. Coordinate plotters

Computers from the YeS EVM [Unified System of Electronic Computers] are used as the central computer: models YeS1033, YeS1045, YeS1055, YeS1060 and BESM-6 [large digital electronic computer], with devices for coupling with the complex's peripheral computer over either computer channels or a telephone-telegraph channel. An example of such a complex is the automated work site for radio engineers (ARM-R), which is based on SM [International System of Small Computers] and Nairi-4-ARM computers.

The ARM-R is a graphic, dialog-type complex that is intended for the automation of engineering, design and technological problems, as well as to support the designer's operational interaction with the SAPR.

The program compatibility, standardization of the equipment interaction and textual and graphic information description structure, the presence of common computer systems elements, magnetic disk and tape storage units, input-output equipment and the significant computational and logic capabilities of the processor of the small computer used in the ARM-R insure [43]:
the solution of an extensive circle of REA design problems related to the reception, storage and reprocessing of information;
data output on punched tape, printers, graph plotters and graphic or character (alphanumeric) displays;
information input in the ARM-R's memory from the central computer, the SAPR, punched cards and tape, magnetic tape, the graphic information encoding unit and various keyboards;
reading or retrieval of information on magnetic tapes and disks;
communication with the SAP's central computer via computer or telephone-telegraph channels;
conduct of a dialog designing mode, with access to programs in both the ARM-R's computer and the SAPR's central computer.

The makeup of the ARM-R was determined on the basis of its functional purpose, as well as the composition and volume of the problems to be solved. The ARM-R was put together on the basis of series-produced hardware manufactured by domestic industry or the countries in the socialist concord.

The makeup of all BGIS SAPR hardware can be divided into five groups:
data processing facilities (computers, magnetic disk (MD) and tape (ML) storage units and communication equipment);
facilities for the input of textual and graphic information and information on machine carriers into the SAPR;
facilities for operational interaction between the BGIS and MSB [microassembly] designer and the system;
facilities for the output of information on machine carriers and the production of design and engineering documents;
facilities for producing special equipment accessories (photographic originals and copies).

Let us discuss in more detail the composition and basic characteristics of ARM-R hardware based on a small type M-400 or SM series computer, so as to evaluate the ARM-R's capability for solving the problems involved in the designing and technological preparation for production of BGIS's and MSB's.

ARM-R Data Processing Facilities. These include the process control computer complex (UVK), magnetic disk and tape information storage units, and devices for matching the information exchange channels. Along with the standard input-output equipment, the UVK contains a small M-400, SM-3 or SM-4 computer that is used as the

ARM-R's host processor, performs the functions of a graphic display processor, and acts as the ARM-R's logic nucleus (controls the ARM-R's equipment, converts information and provides communication with the SAPR's central computer).

The complex of data processing equipment for an ARM-R based on an M-400 UVK includes a memory expansion unit. The total volume of the ARM-R's memory is 48 Kbyte. SM-3 and SM-4 UVK's have improved technical characteristics in comparison with the M-400. The maximum number of addressable 16-bit words is 32 K for the SM-3 and 128 K for the SM-4.

Magnetic disk information storage units are used to store programs for the UVK's disk operating system (DOS), the ARM's DOS, the testing system, the real time system, the package of applied SAPR programs, constants and the archives, and is designed to operate with storage units of the IZOT-1370 type. The magnetic disk storage unit has one constant and one replaceable disk. A magnetic tape storage unit provides for the entry, storage and reproduction of information on standard magnetic tape with an external reel diameter of 216 mm. The entry and readout rate is about 4,000 lines/s.

In addition to this, the processing facilities include units for matching the information exchange channels between the ARM's and central computer's processors over machine or telephone-telegraph channels.

Information Input Facilities. The ARM-R utilizes punched tape, punched card and graphic information input (encoding) devices.

The punched tape and punched card input units are standard computer peripheral gear, so let us discuss only the special SAPR graphic information input units.

The complexity of the design documentation is explained by the presence of variegated conventional symbols defined by YeSKD [Unified System of Design Documentation] and YeSTD [Unified System of Technological Documentation], the meaningful interconnectedness of the images in drawings, and the presence of arbitrarily arranged symbols and texts. Manual entry in a computer of graphic information, which is done with the help of special input languages, is distinguished by low productivity and inadequate protection against human error. Therefore, automating the input process is an urgent problem that is being solved by the creation of automatic and semi-automatic equipment. Automatic graphic information input units convert the traces of lines and symbols on paper, tracing cloth, photographic film or some other carrier into digital computer code. The various designs of automatic graphic input devices can be divided, according to operating principle, into two basic types: scanning and tracking. In scanning devices, the field of a drawing is reviewed line-by-line with the help of scanning systems. Scanning systems are based on ELT's [cathode-ray tube] or electromechanical drives. Tracking units "follow" the lines of a drawing, predicting their possible continuation and searching for the nearest points of a line if there is random drift.

Automatic graphic information input devices are used to enter relatively simple information in a computer: graphs produced on automatic recording devices, the outlines of flat parts. Therefore, they are still not used on a mass basis in REA and MEA SAPR's.

Devices for the semiautomatic input of graphic information have been used more widely in recent years. This is explained by the possibility of identifying the elements of a drawing and synthesizing a complete image of an object with human participation. A number of designs of semiautomatic devices for the input encoding of graphic information (PAKGI) have been developed and realized on the basis of different physical phenomena. Common to all PAKGI's is the principle of distribution of functions between the operator and the machine. The operator analyzes the drawing, picks out the elements that need encoding, and sets the device's working member at certain points on the drawing, after which--at his signal--it automatically computes the points' coordinates and converts them into a digital code. Thus, a PAKGI is used to automate one stage of the entry of a drawing into a computer (computation of the coordinates of points in the drawing that have been designated by the operator).

One of the widely used graphic information input devices is the display. Despite a number of positive qualities, graphic displays have shortcomings (low accuracy and resolution, limited field (screen) size, low productivity, high cost).

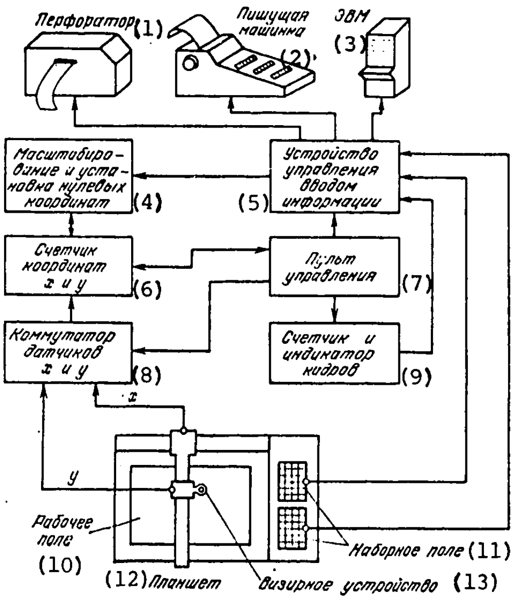

Figure 9.4. Functional diagram of a PAKGI.

Key:

1. Keypunch machine
2. Typewriter
3. Computer
4. Scaling and setting of zero coordinates
5. Information input control unit
6. Reader of x and y coordinates
7. Control console
8. Commutator of x and y sensors
9. Frame counter and indicator
10. Working field
11. Patchboard
12. Plotting board
13. Sighting device

PAKGI's and displays are not mutually exclusive, but supplement each other. In connection with this, the distribution of functions between displays and PAKGI's depends on the nature of the problems to be solved by the system. Most typical is the

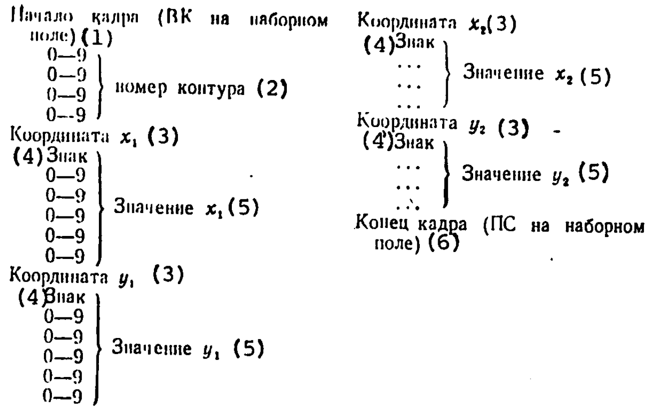

Figure 9.5. Structure of frame for EM-709 PAKGI in "outline" mode.

Key:

1. Beginning of frame (BK on patchboard)
2. Number of circuit
3. Coordinate ..
4. Character
5. Value of ..
6. End of frame (ПС on patchboar^)

distribution where PAKGI's are used to enter the basic mass of graphic information and graphic displays are used for operational monitoring and editing of the information entered in the computer.

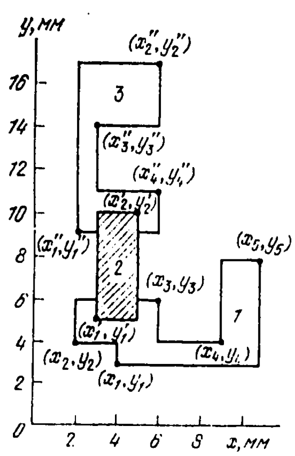

Figure 9.6. Fragment of MSB topology.

Let us discuss in more detail the technical characteristics and functional diagram (Figure 9.4) of a PAKGI of the EM-709 type. It is designed to operate in modes for encoding points, outlines and lines. It makes it possible to correlate the drawing being encoded to an electrically set coordinate network, round off coordinates, work in absolute and relative systems of coordinates, change and turn the coordinate axes through angles that are multiples of 90°, produce a digital display of the determined coordinates, and form the code for a printout, output on punched tape, or transmission to a computer.

Structurally, the EM-709 PAKGI is a plotting board with a control console, a movable patchboard and a sighting device. The EM-709 PAKGI has a plotting board with a working field that makes it possible to encode drawings measuring 900 x 1,200 mm with a coordinate determination error of ±0.2 mm. In connection with this, the origin of coordinates can be moved beyond the limits of the plotting board's working field to a distance of up to 8,200 mm and correlate the drawing being encoded to the electrical grid with 0.1-, 1-, 2-, 2.5- and 5-mm discreteness.

As a result of the EM-709 PAKGI's operation, digital information is produced on punched tape, a "Konsul-260" electric typewriter, or directly in a computer. The

Table 9.2. Result of Encoding Topology of Figure 9.6 With Help of EM-709 PAKGI

Двоичный код ЭМ-709 (1)	16-ричный код (2)	Значение кода (3)	Примечания (4)
10001101	8D	ВК	Начало кадра(5)
10110001	B1	1	Контур № 1(6)
11011000	D8	x	Признак координаты x (7)
10110100	B4	4	$x_1=4$
10110101	59	y	Признак координаты y (7)
00110011	33	3	$y_1=3$
11011000	D8	x	Признак координаты x (7)
10110010	B2	2	$x_2=2$
01011001	59	y	Признак координаты y (7)
10110100	B4	4	$y_4=4$
11011000	D8	x	Признак координаты x (7)
00110110	36	6	$x_3=6$
01011001	59	y	Признак координаты y (7)
00110110	36	6	$y_3=6$
11011000	D8	x	Признак координаты x (7)
00111001	39	9	$x_4=9$
01011001	59	y	Признак координаты y (7)
10110100	B4	4	$y_4=4$
11011000	D8	x	Признак координаты x (7)
10110001	B1	1	} $x_5=11$
10110001	B1	1	
01011001	59	y	Признак координаты y (7)
10111000	B8	8	$y_5=8$
00001010	0A	ПС	Конец кадра(8)
10001101	8D	ВК	Начало кадра(5)
10110010	B2	2	Контур № 2(6)
11011000	D8	x	Признак координаты x (7)
00110011	33	3	$x'_1=3$
01011001	59	y	Признак координаты y (7)
00110101	35	5	$y'_1=5$
11011000	D8	x	Признак координаты x (7)
00110101	35	5	$x'_2=5$
01011001	59	y	Признак координаты y (7)
10110001	B1	1	} $y'_2=10$
00110000	30	0	
00001010	0A	ПС	Конец кадра(8)
10001101	8D	ВК	Начало кадра(5)
00110011	33	3	Контур № 3(6)
11011000	8	x	Признак координаты x (7)
10100010	B2	2	$x''_1=2$
01011001	59	y	Признак координаты y (7)
00111001	39	9	$y''_1=9$
11011000	D8	x	Признак координаты x (7)
00110110	36	6	$x'_2=6$
01011001	59	y	Признак координаты y (7)
10110001	B1	1	} $y''_2=17$
10110111	B7	7	
11011000	D8	x	Признак координаты x (7)
00110011	33	3	$x''_3=3$
01011001	59	y	Признак координаты y (7)
10110001	B1	1	} $y''_3=14$
10110100	B4	4	
11011000	D8	x	Признак координаты x (7)
00110110	36	6	$x''_4=6$
01011001	59	y	Признак координаты y (7)
10110001	B1	1	} $y''_4=11$
10110001	B1	1	
00001010	0A	ПС	Конец кадра (8)

Key:
1. EM-709 binary code
2. 16-bit code
3. Meaning of code
4. Notes
5. Beginning of frame
6. Outline No .
7. Sign of . coordinate
8. End of frame

Output information is grouped in the form of frames corresponding to the type of information being encoded: point, line, outline, or code. As an example, Figure 9.5 depicts the structure of the frames of an outline, while Figure 9.6 is a fragment of the topology of an MSB. Table 9.2 shows the information obtained as the result of the encoding of the topology in Figure 9.6. In the binary codes presented in the table, "1" corresponds to a hole punched in a tape. This fragment was encoded in an absolute reading mode with a grid with 1-mm spacing. All three outlines were plotted clockwise from the lower left corner, with the encoding being done in terms of the corner.

The EM-709 PAKGI makes it possible to achieve a significant increase in labor productivity when entering graphic information in a computer, to a rate of 350-400 points/h or more.

Facilities for Operation Interaction With the ARM-R. These include character and graphic displays, electric typewriters and teletypes.

Of these facilities for operational interaction of a designer with the SAPR, the electric typewriter and the teletype are devices for conducting a limited dialog with symbols. They are frequently used as the operator's console for entering or removing several symbols or words when controlling the computer's operation.

For the conduct of a dialog in symbol form between a designer and the SAPR, displays based on cathode-ray tubes, with both symbol and function keyboards, are the most efficient.

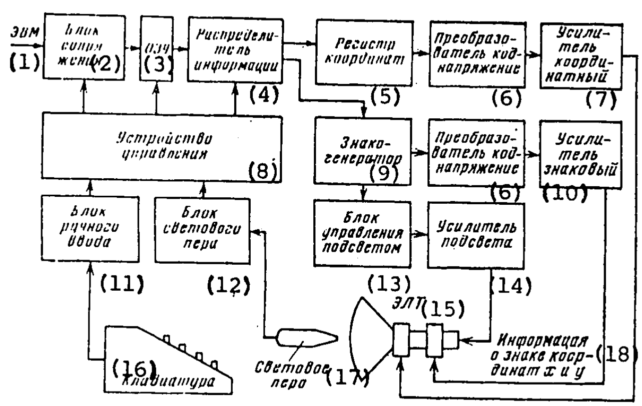

Figure 9.7. Functional diagram of graphic display.

Key:

1. Computer
2. Coupling unit
3. Operational memory
4. Information distributor
5. Coordinate register
6. Code-to-voltage converter
7. Coordinate amplifier
8. Control unit
9. Sign generator
10. Sign amplifier
11. Manual input unit
12. Light pen unit
13. Illumination control unit
14. Illumination amplifier
15. ELT
16. Keyboard
17. Light pen
18. Information on signs of x and y coordinates

Figure 9.7 is a functional diagram of a graphic display. The use of ELT's in the display requires the solution of the problems involved in controlling ray deflection with the help of signals from the computer. In the computer the signals normally appear in digital form, but since analog signals (such as voltage) are required to control an ELT, a digital-to-analog code-to-voltage converter is used. Precise observance of the temporal relationships is necessary in order to control ELT's; this is provided by the control and synchronization units. Modern ELT's have little afterglow, so in order to obtain a stable, nonflickering image under normal workplace illumination, an image regeneration frequency of 30-40 cycles per second is required.

Different methods are used to form the image on the display screen: point, vector and step-by-step modes or a mode utilizing straight line segments and short vectors [45]. In the point mode, the image is formed from points on the screen that are addressable separately and have coordinates that are given as x and y in the registers. Displays have ELT's with horizontal and vertical arrays ranging from 256 to 4,096 addressable points; for solving problems with the SAPR, displays with arrays measuring 1,024 x 1,024 points or more are normally used.

In the point mode of a display for laying out some figure consisting (for example) of 100 points, it is necessary to organize a computation cycle that repeats itself 100 times and consists of approximately the following sequence of operations: confirm that i > 100 or not; send the values of x_i and y_i into the display's registers; illuminate point (x_i, y_i); increase i by 1. This sequence of operations--a program in the commands of the specific display--will contain 5-10 commands. In order to execute such a program on, for example, a YeS 1020 computer (with an operating speed of about 20,000 operations/s), it takes about $0.5 \cdot 10^{-3}$ s, while execution of an entire cycle requires about 0.05 s. Since it is necessary to have regeneration (repeated extraction of information from the computer every 0.03 s), the maximum number of reproducible points for the given computer must not be more than 100. In order to obtain an image consisting of 1,000 points, it is necessary to have a computer with a productivity rate of at least 300,000 operations/s (such as an M-400). From this it is obvious that a point display is useful for images of simple figures and sets of individual points.

In order to depict on a display's ELT diagrams and drawings consisting of a set of lines, the vector mode is used. In this mode, Δx_i and Δy_i give the displacements along the corresponding axes from the previous point depicted on the screen. The basic advantage of the vector mode is the smaller OZU [operational memory] capacity and the possibility of producing a quite complex image on the screen.

The substantial savings in memory in the vector mode as opposed to the point mode can be demonstrated with a simple example. In order to store information about the framework of a sketch drawn around the working field (1,000 x 1,000 discrete points of the array) in the point mode, it is necessary to store 4 x 1,000 point coordinate values; in the case of the vector mode, it is sufficient to store the coordinates of the initial point and the values of four increments along each of the x and y axes.

As a rule, displays operating on the vector generation principle utilize several operating modes. The straight-line-segment (vector) mode is used to produce long lines. When the image contains many curved lines, the short-vector mode is used. In this mode, in order to record ΔX and ΔY it is sufficient to use 4 bits instead of the 8-10 bits required in the straight-line-segment mode. This makes it possible to reduce the memory capacity even further.

Displays can usually function in different modes, and the capability of changing from one mode to another is provided in order to insure optimum reproduction of different parts of an image. This can be done by various methods. One of them is the designation of the appropriate mode parameter in the special commands of the program controlling the functioning of the display.

The designer's work with a BGIS SAPR involves constant participation in the design process, correction of the decisions made by the computer, modification of the initial conditions and, finally, active intervention in the process of the solution of problems that cannot be completely formalized. Thus, the designer needs both hardware and software that give him the capability to enter the necessary information in the computer on an operational basis.

A SAPR usually has as part of its linguistic capability certain graphic languages, while the operators can have a line-by-line entry capability that makes it possible to enter geometric information from such operational interaction devices as electric typewriters, teletypes, or the symbol and function keyboards of the displays. During the process of designing a BGIS, it is most convenient to conduct a dialog on the level of geometric images, where the designer has the ability to modify some figure or sketch fragment displayed on the ELT for analysis. In order to insure graphic interaction there exist such devices as a light pen, a tracking cross, analog input devices of the myshek [translation unknown] type, a tracking ball, a coordinate knob and so on [45].

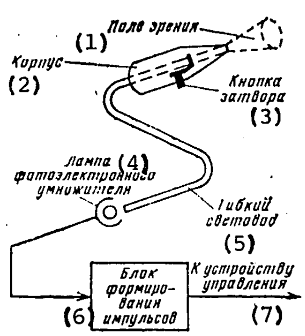

Figure 9.8. Block diagram of a light pen for a display.

Key:
1. Field of view
2. Housing
3. Shutter button
4. Photoelectronic multiplier bulb
5. Flexible light guide
6. Impulse formation unit
7. To control unit

Let us discuss the light pen used in the Soviet-made YeS7064 and EPG-400 displays. Figure 9.8 is a block diagram of the light pen. If a point or line is in the pen's field of view, an impulse is generated in the photomultiplier every time the given element of the image is regenerated. This impulse is formed and transmitted to the display's control unit. The output impulse appears simultaneously with the image of the element on the screen. This makes it possible to determine the specific indicated element of the image.

Let us examine the technical characteristics and capabilities of the ARM-R's symbol and graphic displays.

The "Videoton-340" symbol display in the ARM-R is used as a systems console for the reception of control information, such as a directive from the BGIS and MSB developer, and the depiction of messages, as well as for the depiction and editing of symbol information. On the display's screen, which measures 200 x 140 mm, it is possible to reproduce a text of 16 lines, with up to 80 symbols per line. The display's operating modes are as follows: autonomous, operation with the computer, information transmission from the buffer memory into the computer and parallel printing on a typewriter of the buffer memory's contents. The display has the following text-editing capabilities: clearing of the image on the screen, setting of a tag in the first position of the first line, movement of a tag in four directions, tabulation, replacement, insertion, deletion of a character, insertion and deletion of a line, memory protection, underlining, raising of a frame one line upward and replacement of the last line.

The EPG-400 graphic display in the ARM-R is used to enter, depict and edit graphic and symbolic information on an ELT screen. The display utilizes a channel that gives direct access to the computer's memory in order to register an image on the screen. It provides for the depiction of information in the following modes:
plotting of symbols;
plotting of long vectors, star vector points and right angles with absolute and relative assignment of coordinates;
plotting of short vectors with relative assignment of coordinates;
plotting of graphs with automatic increments along the x and y axes;
marking arbitrary positions with any symbol.

Images with the following parameters can be depicted on the EPG-400's screen: image size--240 x 240 mm; number of addressable points--1,024 x 1,024; number of line modulation levels--8; types of lines--4 (continuous, dotted, dash, and dot and dash).

The graphic display provides for the entry of information in the computer by means of symbol and function keyboards and a light pen that has resolution no worse than seven units of the array.

The ARM-R complex contains the following documentation facilities: an alphanumeric printer, a plotter and a microfilming unit.

The experience gained in automating technological design work shows that even a small amount of manual intervention in the drawing up of technical documents causes their quality to deteriorate, so it is not advisable to use a SAPR that does not provide automatic registration of the design process's results in the form of documents acceptable to the archive services of enterprises.

An alphanumeric printer (ATsPU) is used for the output of textual documentation (specifications, tables of coordinates and so on). The ARM-R has an ATsPU that features sequential printing with a mosaic set of symbols. Each symbol is formed by a point-type mosaic matrix of 7 x 7 elements. The printing is done on perforated paper up to 420 mm wide, with up to 4 copies. The maximum printing rate is 180 symbols per second.

Plotters controlled by the computer or perforated or magnetic tape are used for the production of graphic information (graphs and diagrams, functional and electrical diagrams, design and engineering drawings) in a BGIS SAPR. Plotters are semi-automatic electromechanical drawing devices that consist of a recording unit (Figure 9.9) that reproduces an image on some carrier or another (paper, photographic film and so on), a unit that controls the plotting process, and a unit for the entry and conversion of the input information.

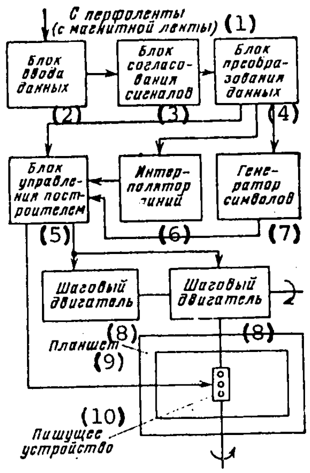

Figure 9.9. Functional diagram of a plotter.

Key:
1. From punched (magnetic) tape
2. Data input unit
3. Signal matching unit
4. Data conversion unit
5. Plotter control unit
6. Line interpolator
7. Symbol generator
8. Step motor
9. Plotting board
10. Writing device

The functioning of plotters is based on the principle of converting input commands into proportional movements of a writing unit. The writing assembly is put into motion by step electric motors (or direct-current electric motors) through mechanisms for converting rotary motion into progressive motion. Depending on the form of the documentation being produced, the following types of writing devices are used: pens, rapidografy [translation unknown], light or laser recording units or a precision engraving unit and so on. Plotters are equipped with several (from one to six) writing devices that are filled with different inks and draw lines of varying thickness.

When both motors revolve alternately or simultaneously, the writing unit draws horizontal (vertical) or slanted lines. A linear interpolator is used to draw lines with an arbitrary inclination. Modern plotters are also equipped with linear-circular and parabolic interpolators for drawing second-order curves. For the production of drawings in accordance with YeSKD and YeSTD requirements, plotters have interrupters for drawing dash, dotted and other non-continuous lines. Legends are inscribed on drawings with the help of a pen or are printed by special symbol-printing heads that are part of the plotter.

As far as their design is concerned, plotters are either of the plotting board or the drum type. Drum plotters are used for the operational output of information on paper from a roll. Plotting-board plotters are more accurate than the drum types, and are used to produce drawings and photographic templates.

The specifications of several types of plotters are presented in Appendix 1.

Plotters have systems of control commands that are formulated in accordance with their capabilities and purpose. The system of commands for the AP-7252 plotter that is part of the ARM-R's hardware complex is presented in Table 9.3. It is easy to understand the rules for encoding a graphic image by examining an example of the control program for drawing the figure shown in Figure 9.10. When operating in the increment mode, the segment that is being drawn or the transition (with the writing device lifted from the carrier) is a number of steps or half-steps in 16th form. The control program consists of a heading, data and a graph completion indicator. The heading consists of the commands that determine the plotter's operating mode. The data consist of a sequence of increments in the coordinates of points in the graph that give the magnitude and direction of movement of the writing device. The commands are given as two bytes. The first byte contains command indicator 2A,

Table 9.3. System of Commands for AP-7252 Plotter

Наименование команды (1)	16-ричное представление (2)
(3) Режим приращений	04
(4) Инкрементальный режим	26
(5) Работа с полным шагом	15
(6) Работа с полушагом	16
(7) Выбор пишущего устройства № 1	21
(7) Выбор пишущего устройства № 2	22
(7) Выбор пишущего устройства № 3	23
(8) Пишущее устройство опустить	06
(9) Пишущее устройство поднять	07
(10) Конец последовательности команд	81
(11) Конец графика	82

Key:
1. Name of command
2. 16th-form representation
3. Mode of increments
4. Incremental mode
5. Operation with full step
6. Operation with half step
7. Choice of writing device No .
8. Lower writing device
9. Lift writing device
10. End of sequence of commands
11. End of graph

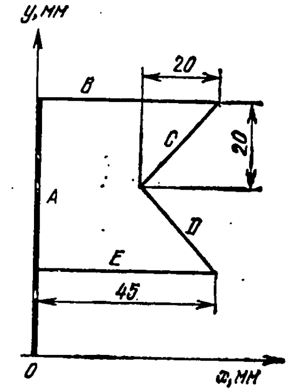

Figure 9.10. Example of topological figure (▬▬▬ = writing device No 1; ----- = writing device No 2).

while the second contains the command code (see Table 9.4). The increments in the coordinates of the points in the graph are given by four bytes: two bytes for Δx and two for Δy. Negative increment values are given in a supplementary code.

One promising documentation method is micrography. Micrography makes it possible to solve most problems involved in the long-term storage and circulation of information in SAPR's and ASUP's [automated production control system], including those connected with reducing the volume of the document depository, achieving a significant reduction in the time required to retrieve needed information, and reducing the mass, volume and--consequently--cost of the documents. The solution of all these problems is possible because of microminiaturization of documents with complete preservation of their special graphic features.

Photographic films in different formats are used as microcarriers. Microcarriers are classified as continuous (microfilm) and discrete (microcards). Microfilm is normally used for the archival storage of documents and the creation of an insurance stock of documents.

Discrete microcarriers are used to create flexible information systems in ASUP's and SAPR's. As a rule, a discrete microcarrier is a card made of photographic film on either a paper or a plastic base in combination with the film. The most widely used microcards measure 105 x 148 mm and are called microfiches. A microfiche has a visually readable heading, and when 20-fold reduction is used, 72 pages of text can be placed on it. In connection with this, a reduction in the volume of the printed unit by a factor of 70-75 can be achieved, which makes it possible to create thematic card libraries and archives of typical BGIS SAPR technological design solutions that contain a great deal of information.

Table 9.4. Program for Drawing Topology of Figure 9.10 With AP-7252 Plotter

Команды (1)	Комментарии (2)	
2A 04	Работа в приращениях (3)	
2A 15	Работа с полным шагом (4)	
2A 21	Пишущее устройство № 1 (5)	
2A 06	Пишущее устройство опустить (6)	
80 00	$\Delta x = 0$	A, пишущее устройство № 1 (5)
84 B0	$\Delta y = 60$	
2A 22	Пишущее устройство № 2 (5)	
83 80	$\Delta x = 45$	B, пишущее устройство № 2 (5)
80 00	$\Delta y = 0$	
FE 70	$\Delta x = -20$	C
EF 70	$\Delta y = -20$	
81 90	$\Delta x = 20$	D
FE 70	$\Delta y = -20$	
FD 7D	$\Delta x = -45$	F
80 00	$\Delta y = 0$	
2A 82	Конец графика (7)	
2A 81	Конец последовательности команд (8)	

Key:
1. Commands
2. Comments
3. Work in increments
4. Work with full step
5. Writing device No .
6. Lower writing device
7. End of graph
8. End of sequence of commands

For the production of special technological equipment, in addition to the ARM-R equipment facilities, BGIS SAPR's and ASTPP's [automated system for the technological preparation of production] also include devices such as a koordinatograf [translation unknown] and a microphotocomposition unit.

In order to produce the originals of BGIS phototemplates, program-controlled koordinatografy are widely used at the present time. They consist of a drawing table, a device for information input from punched tape, and a control unit. The basic technical parameters characterizing a koordinatograf are its speed and drawing accuracy. These parameters are closely interrelated: increasing the drawing speed leads to a lowering of accuracy and vice versa. The type of koordinatograf chosen depends on the required accuracy in the production of the phototemplate originals. Modern program-controlled koordinatografy have a drawing accuracy of 20-150 μm at drawing speeds of 2.5-25 m/min.

One widely used program-controlled koordinatograf is the EM-703 [16], which combines high productivity (up to 5.5 m/min) with high accuracy (±50 μm) and a large field for movement of the working tool (1,200 x 1,200 mm), which has a linear-circular interpolator that makes it possible to cut out both rectangular and curvilinear outlines. This koordinatograf contains a high-speed tracking drive for moving the carriages that is based on direct-current motors, as well as a system for continuous, automatic orientation of the tool's cutting edge in the direction of the cut. The presence of a special device makes it possible to use the koordinatograf to draw on photosensitive material with a light beam during the designing of IS and BGIS wiring cards. The coordinate table insures high accuracy of the movements over the entire working field because of its rigid design and the presence of photoelectric sensors and mechanisms for the correction of screw errors.

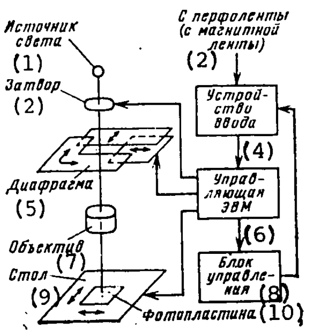

Figure 9.11. Block diagram of photocomposition unit.

Key:
1. Light source
2. From punched (magnetic) tape
3. Shutter
4. Input device
5. Diaphragm
6. Control computer
7. Lens
8. Control unit
9. Table
10. Photographic plate

The original of a phototemplate produced on the koordinatograf is photographed with a special precision camera in order to obtain an intermediate original, which is then copied on a glass substrate.

In order to insure the required degree of integration, accuracy and productivity in the production of special technological equipment for BGIS's and MSB's, there has begun a transition to image generators, which are program-controlled opticomechanical equipment for the production of primary phototemplate originals. The primary originals can be used directly for the production of standard phototemplates on photorepeaters [16] without preliminary reduction.

The method of image generation by photocomposition is the most widely used one. Figure 9.11 is a diagram of a photocomposition unit. The phototemplate is divided, with the necessary angular orientation, into elementary rectangles of different sizes and with different side orientations. These rectangles are then positioned highly accurately with the help of the coordinate table and then imprinted in the necessary places on a photographic plate. The advantage of photocomposition consists of higher productivity, and when the coordinate table and the control system are designed appropriately, this method provides very high accuracy.

The EM-549 microphotocomposition unit has a working field of 140 x 140 mm, with positioning accuracy of ±0.5 μm. The size of the image elements that are generated is 0.30-30 mm. The unit's productivity is 2,400 exposures per hour. The EM-549 microphotocomposition unit utilizes a coordinate table on an air cushion, while movement along the axes is accomplished with the help of a motor with a developed rotor. The unit's large working field makes it possible to use it in the production of high-quality thin-film BGIS's. Two working modes (photocomposition and scanning) make it possible to use it not only to generate phototemplates, but also as a photorepeater. Its broad scaling range (2-10) makes it a general-purpose device.

Specific systems for automating the design and production preparation processes are put together on the basis of SAPR hardware. The hardware of SAPR's for different purposes are, as a rule, identical in functional makeup. They differ in the characteristics of the individual devices (operating speed of the computer, magnetic disk memory capacity, accuracy and drawing speed of the plotter, printing speed for textual documents and so forth). The software is basically individualistic and is determined by the specialization, purpose and quality of the SAPR and the technological preparation for the production of BGIS's.

SECTION 9.4. METHODS AND ALGORITHMS FOR AUTOMATED DESIGNING OF BGIS'S AND MICRO-ASSEMBLIES

Two methods--automatic and interactive--have been developed in the process of automating the designing of BGIS's.

The automatic design method's essence is that synthesis of the design is carried out only by the SAPR's facilities, according to a certain algorithm, while the designer gives the initial data, sets off the design process, and evaluates and approves the decision that is produced.

In the interactive method of design, there is interaction between the designer and the SAPR facilities in the synthesis of the design. It is based on that division of functions between them that makes it possible to use the creative qualities of man and the computational power of computers to solve a formulated problem in the best combination and as efficiently as possible.

In the automatic synthesis of a BGIS design, the design process is divided into several stages because of the complexity of the solution of the problem as a whole and the lack of general, effective optimization criteria. The design process is usually divided into the following stages: layout of the BGIS, calculation of the pellicular elements, placement of the pellicular elements and discrete components on the substrate, and layout of connections. When the design process is automated, each stage has its own specialized algorithms and criteria. Communication between the stages is realized through transformable computer models of the BGIS and special criteria. The special criteria of the individual stages allow for the special features of the subsequent design stages; for instance, during BGIS layout the number of external leads is minimized, thus reducing the number and length of connections between the BGIS's. In the placement stage, using the criterion of minimum connection length, the total length of the connections is reduced as they are being laid out on the BGIS substrate.

BGIS layout differs little from the layout of cells on printed-circuit cards, and the same algorithms and criteria are used for the solution of these problems [46].

Layout algorithms can be categorized as sequential, parallel-sequential and iterative. In sequential algorithms, the layout process is realized sequentially, with one of the design elements being added to the next MSB in each stage. In parallel-sequential algorithms, some initial set of groups of elements is first singled out and then distributed by assemblies, with due consideration for the layout criteria and limitations. Sequential and parallel-sequential algorithms are used to create the elementary layout variant for the given limitations on the number of elements and leads on the MSB substrate.

Iterative layout algorithms are used to improve some initial layout variant in accordance with an adopted criterion. The basic optimization criteria are a minimum number of BGIS's and a minimum number of interassembly connections, while the limitations are on the number of elements in the BGIS's and external leads on the substrate.

During the stage of placement of pellicular elements and discrete components on the BGIS substrate, their optimum spatial positioning on the substrate is determined. A frequently used placement optimization criterion is the criterion of minimum total length of the connections.

Depending on the structural features of a BGIS, it is possible to use criteria that minimize the number of connection intersections or layers of connections on the substrate.

Placement problems can be divided into two types: placement of structurally monotypical components modeled on the substrate by points in previously given coordinates, and placement of heterotypical pellicular elements and discrete components, having a great variation in geometrical dimensions, on a continuous model of the substrate without fixing their positions. Problems of the first type are typical for digital devices. There are several types of algorithms for the solution of these problems [46]:

placement algorithms that use mathematical methods for solving function problems. For placement modeled by a linear function problem, a Hungarian algorithm is used, while for placement modeled by a quadratic function problem, the method of branches and boundaries is used;

structural placement algorithms utilizing a sequential or parallel-sequential process for the arrangement of components at positions given by coordinates create a placement that can be an initial one for subsequent optimization according to a certain criterion;

in iterative algorithms there is repositioning of the components (or groups of them) after the initial placement is produced by one of the structural algorithms. Iterative algorithms require substantial expenditures of computer time and are used to obtain a final solution.

The following recommendations on the use of placement algorithms can be made for digital BGIS's. When there are limited computer time resources, relatively fast structural algorithms for initial placement should be used. Among them, the simplest ones from the realization viewpoint are algorithms for placement based on compendency. For relatively small problem dimensionalities, these algorithms can also be used to determine the final placement.

In order to obtain more accurate results, it is advisable to combine a fast initial algorithm with an improving iterative one. Practice shows that this gives better than when the initial positioning is obtained by some method that is more or less random.

Among the iterative algorithms, the most effective methods are based on paired rearrangements of elements in truncated neighborhoods of interrelated elements, which makes it possible to reduce the time substantially while maintaining the same level of accuracy in the result.

Problems of the second type are typical of digital-to-analog and analog devices, which have a greater (by factors of tens to hundreds) variety of geometrical dimensions of elements and components. These problems are frequently solved by the use of interactive methods for arranging elements and components on the substrate with the help of operational interaction facilities.

In Section 9.2 it was shown that modern SAPR hardware consists of devices that expand SAPR and designer capabilities significantly. For operational interaction of the designer with the system (that is, the conduct of a dialog), symbol and graphic displays are used; for input of graphic information into the system--PAKGI graphic information encoders; for the production of documentation and original photographs of the layers--plotters, microfilming units, koordinatografy and microphotocomposition devices.

The presence of these special facilities, computers of the SM series, the ARM's disk operating system and a package of applied programs providing a mode where the designer can conduct a dialog with the system, made it possible to create methods and algorithms for synthesizing the designs of BGIS's and MSB's.

Since the complex of BGIS SAPR hardware contains a graphic display and a package of applied graphic programs, it is possible to create an impression of universality of these operational interaction facilities for the interactive solution of the indicated problems when designing BGIS's. In reality, the EPG-400 graphic display has a screen measuring 240 x 240 mm, while the size of the light beam on the display's screen is focused to a diameter of 0.3-0.5 mm. Thus, one or two lines per millimeter can be distinguished on the display's screen. In order to represent on the display's screen fully distinguishable elements of BGIS and MSB topology having a minimum size of several tens of microns, it is necessary to represent the topology with a magnification scale of 20:1, 40:1, or even more. From this it is obvious that an MSB substrate measuring 24 x 30 mm can be represented on such a scale only in the form of separate fragments comprising one-sixth or less of the area covered by the substrate. Therefore, in the face of such great fragmentation, dialog designing of BGIS's consisting of tens and hundreds of elements and components cannot be sufficiently optimum because of the "nonreviewability" of the plan on the display's screen. The interactive arrangement method makes it possible to find the first acceptable solution, since the optimization inherent in multivariant planning is made more difficult. Besides this, the interactive method is more labor-intensive and requires considerable amounts of time for the designer to interact with the SAPR.

CHAPTER 11. AUTOMATING CONTROL OF THE TECHNOLOGICAL PROCESSES INVOLVED IN BGIS AND MSB PRODUCTION

Automating the production of BGIS's encompasses a broad circle of problems, ranging from automating the design process and the technological preparation for production to automating the direct control of the technological operations and processes and production sections as a whole. The improvement of the production process on the basis of automation of the control of technological processes serves as a means for increasing the productivity of labor, the quality of the articles produced and the profitability of production.

At the present time most systems for the automated control of technological processes (ASUTP) involved in the production of microelectronic equipment are based on control computers. Modern facilities for the automatic collection and processing of information make it possible to solve the problems involved in automating the control of technological processes and obtain results that increase the productivity of labor, the quality of the output and production efficiency, which were impossible to achieve with other control facilities and methods.

The introduction of ASUTP's makes it possible to do the following [13]:
realize a process with maximum productivity by automatically allowing for deviations (drift) occurring in the technological parameters and the properties of the raw materials and semifinished goods, as well as changes in environmental parameters, operator error and so on;
control a technological process by constantly allowing for the dynamics of the plan-actuality relationship for the list of products being manufactured (rated values, classes, accuracy and quality groups) by timely resetting of the technological equipment's modes, redistribution of the work among monotypical equipment and so on;
realize automatic control, according to an optimum algorithm, under conditions that are harmful or dangerous for human life.

It is important that the introduction of an ASUTP in a complex with facilities for the mechanization of manual labor (industrial robots) makes it possible to use labor resources efficiently and solve the problem of the deficit of qualified and unqualified personnel. In addition, the introduction of an ASUTP produces (in principle) not only a direct economic (or socioeconomic) effect, but also makes it possible to obtain a large secondary effect, since it requires an improvement in the overall level of technology, organizational orderliness of the production process, and production efficiency.

All of this shows how essential the introduction of control computers in technological production processes is for scientific and technical progress in radio equipment construction.

11.1. STRUCTURE AND COMPOSITION OF ASUTP'S FOR THE PRODUCTION OF BGIS'S AND MSB'S

At the present time, integrated automation of technological processes on the basis of a systems analysis approach is widely used; this means not the development of an ASUTP for a given technological process, but technological process-ASUTP systems [2].

The concept "technological process" as an object of control includes, in particular, the technological equipment, with the exception of sensors and actuating members that are structural elements of the equipment but are actually part of the ASUTP hardware. In the following explication, therefore, control of a technological process means control of the technological equipment's operating modes.

Henceforth, the term "controlled technological process" will be understood to mean a process for which the monitorable input effects (controlling, controlled) have been determined, the deterministic or probability relationships between the input effects and the output parameters of the article being produced have been established, and methods for the automatic measurement of input effects and output parameters and methods for controlling the process have been developed [2]. Thus, a controlled technological process is one that, in principle, has been prepared for the introduction of an ASUTP; that is, for the creation of a technological process-ASUTP system.

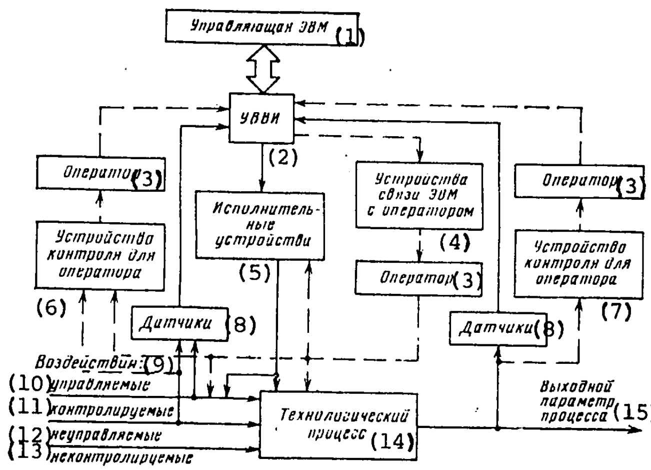

Figure 11.1. Generalized block diagram of a technological process-ASUTP system.

Key:

1. Control computer
2. Information input-output devices
3. Operator
4. Devices for computer communication with operator
5. Actuating members
6. Monitoring device for operator
7. Monitoring device for operator
8. Sensors
9. Effects
10. Controlled
11. Monitored
12. Uncontrolled
13. Unmonitored
14. Technological process
15. Output parameter of process

Figure 11.1 is a generalized diagram of a technological process-ASUTP system. The ASUTP in this system must predict, on the basis of an analysis of the measured values, the path of the process and realize that plan of controlling effects such that, at a certain moment of time, the state of the process corresponds to some value of the generalized process quality criterion that is close to optimum. As is obvious from Figure 11.1, in addition to the control computer the ASUTP contains a complex of information input-output devices (UVVI), actuating members and sensors that are connected, on the one hand, to the computer through the UVVI and, on the other, to the controlled object. In a special case, measurement of the technological parameters and control of the actuating members can be carried out through the operator (dash lines in Figure 11.1).

The control functions are realized groundlessly, automatically, or with the participation of man in individual (or all) circuits. At the present stage, for all practical purposes, primarily in preparatory, monitoring and assembly operations, without the participation of man it is extremely difficult to realize control of technological processes, so--as a rule--an ASUTP also contains different devices for communicating with operators (signal panels, mnemonics, displays, manual information input and output consoles).

Among other production processes, the production of BGIS's and MSB's is distinguished by the multiplicity of the technological processes, which differ in the nature of the procedures (discrete, continuous, continuous-discrete), the physical essence (vacuum, electrochemical, thermochemical and so forth), and the organizational indicator (group or individual processing).

An analysis of the different technological processes and operations involved in the production of BGIS's and MSB's and an investigation of technological process-ASUTP systems make it possible to formulate the characteristic features of processes as objects of control:
substantial dependence of the results of a subsequent operation in a single technological process on the preceding one;
the diversity of the raw materials and relative instability of their properties;
the presence of temporally changing uncontrollable and even unmonitorable effects;
a tendence toward changing over to highly productive, mechanized realization of the process (complexly mechanized technological lines), which practically eliminates the possibility of manual control of the process, and allowing for the effect of disturbing (controllable and uncontrollable) effects;
the presence of a large number of operations in mass production that were previously done manually (monitoring, assembly, installation and others).

For different technological and production processes (spraying, painting, vzhiganiye [translation unknown] and others), these factors are not of equal weight as far as their effect on the quality of finished articles is concerned, although it is essential that in the production of practically any BGIS or MSB, the percentage of output of serviceable articles is considerably less than 100 percent.

A no less important factor (specific for the electronics and radio industries) that reduces production efficiency is the continuously changing portfolio of orders when there is an extensive goods list of rated-value types and classification groups of articles being produced. Using old technology and production control methods, the timely and complete satisfaction of a request is an almost unsolvable problem.

These special features in the production of BGIS's and MSB's determined the objective necessity of introducing automated control systems of both separate determining technological operations and as technology and production as a whole.

Modern ASUTP's are constructed on the basis of control computers that receive information about the course of a technological process, process the information in accordance with the control algorithm that is entered in the memory in the form of a package of programs, and transmits regulating actions to the actuating members or advises the operating personnel through information display facilities.

In practice it is important to know what functions an ASUTP can perform relative to a specific technological process and what are the sources of the economic effect achieved by introducing the system, with due consideration for the functions being

Table 11.1. Classification of ASUTP's According to Functional-Algorithmic Features

Class and Basic Characteristics of ASUTP's	Basic Functional Features	Typical Examples of Controlled Objects	Basic Sources of Economic Effectiveness
1st class--systems of logic-program control of one or a group of monotypical installations.	Direct digital control according to a rigid or semi-rigid program compiled in accordance with course of the technological process, in mode of time sharing between controlled units; depending on values of input (measured) variables, the program provides for conditional and unconditional transitions.	Group of BGIS and MSB monitoring stations. Group of vacuum unit evacuation stations. Group of substrate cutting units. Installations for producing intermediate photo-templates. Units for processing an electron beam.	Increase in productivity of labor. Sharp reduction in operating personnel errors and defective goods resulting from errors. Stabilization of technological process. Reduction in personnel when multiprogram control is used.
2nd class--systems for optimum control of a technological process or operating modes of technological installation.	Solution of optimization of a problem on the basis of information received from the controlled object and mathematical models that have been adopted. Working out of regularizing actions or advice for operator on real time scale	Section of circuits for vzhiganiye of thick-film resistors and BGIS conductors. Line for manufacturing precision pellicular condensers. Unit for anodizing precision resistive substrates.	Increase in percentage of output of serviceable substrates. Improvement in quality (accuracy) and reliability of MEA goods. Fulfillment of given goods distribution for MEA articles being produced.
3rd class--systems for integrated control of a technological line or section.	Automatic or semiautomatic collection, processing and visual depiction of technological and organizational production information, control of course of technological process by operating personnel.	Group of technological lines for production of BGIS's. Production of substrates and cakes for BGIS's. Shop for galvanic coatings of MEA articles.	Reduction of losses of working time and equipment down time in sections and technological lines. Improvement in percentage of serviceable goods output and quality of articles because of improvement in operational nature of control by personnel.

performed. A certain degree of clarity in this question is made possible by the classification of ASUTP's by functional-algorithmic features (Table 11.1) proposed in [15]. Let us examine in more detail the functions of ASUTP's on the basis of this classification. It is necessary to allow for the fact that the functions performed by the systems in different classifications can overlap in a number of cases.

The first class includes ASUTP's with the simplest control algorithms; in other words, there is a completely controlled technological process that was previously under the control of an operator. The basic function of the central processor of such ASUTP's is to execute control programs with automatic time distribution. The control algorithm is an established sequence of logical operations with conditional or unconditional transitions from one operation to another.

Systems of the first clsss include, in particular, direct multichannel digital regulation systems or systems for the direct digital control of equipment, such as a microphotocomposition unit.

The introduction of such automated systems makes it possible to:
eliminate incorrect human actions;
use, for control purposes, information in volumes that exceed considerably the knowledge of a single operator;
operationally and accurately change the control program in accordance with a change in the technological process's parameters;
increase equipment productivity as the result of eliminating manual control operations;
realize logic-program control of those operations and processes that man cannot control accurately and on a timely basis because of his relatively slow reaction to a change in the course of the process.

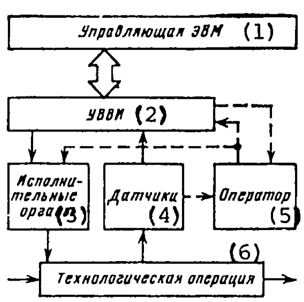

Figure 11.2. Block diagram of a system for the logic-program control of a single technological operation (installation).
Key: 1. Control computer
2. UVVI
3. Actuating members
4. Sensors
5. Operator
6. Technological operation

The block diagram of an automated system for the logic-program control of a single technological operation is shown in Figure 11.2.

The use of a computer for program control makes it possible to adjust control algorithms flexibly and operationally and, in addition, realize multiprogram control of a group of technological operations (installations) in a time-sharing mode. In the general case, the computer's memory stores the control programs, the number of which corresponds to the number of control objects, while the general program--the dispatcher--organizes their multiprogram operating mode. Such systems have the following advantages over individual program control facilities:
a reduction in the total volume of electronic equipment and a corresponding reduction in capital expenditures for the automation of a technological process;

the possibility of--parallel with the direct program control of individual operations--solving problems related to centralized monitoring, accounting for the work being done and monitoring the equipment's functioning, overall control and, in the case of control of monotypical equipment, redistributing the work;
the possibility of changing over to optimization of the control of the technological process;
bilateral communication with integrated production control systems.

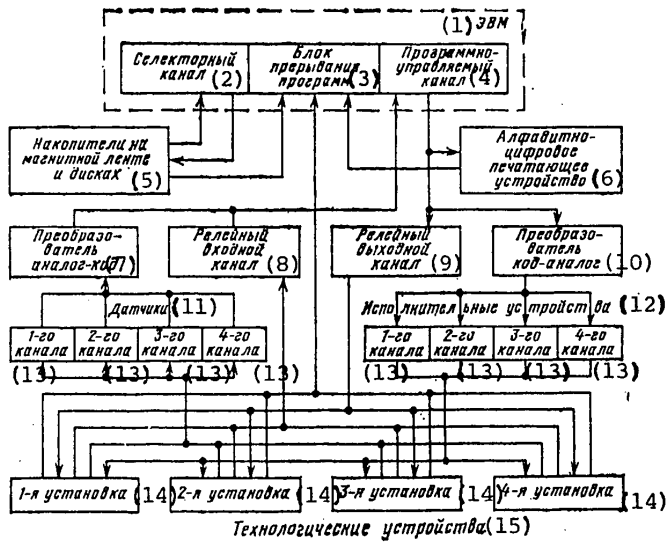

Figure 11.3. Block diagram of a system for logic-program control, with the help of a single computer, of a group of technological units.

Key:
1. Computer
2. Selector channel
3. Program interrupt unit
4. Program-controlled channel
5. Magnetic tape and disk storage units
6. Alphanumeric printer
7. Analog-to-code converter
8. Relay input channel
9. Relay output channel
10. Code-to-analog converter
11. Sensors
12. Actuating members
13. Channel No .
14. Unit No .
15. Technological devices

Figure 11.3 is the block diagram of a system for the program control of a group of technological units (operations) with the help of a single computer.

The second class includes ASUTP's that, on the basis of a deterministic or statistical model of a process (see Section 10.2) entered in the computer's memory, solve the problems involved in optimizing the process for the purpose of satisfying some quality indicator. As has already been mentioned, for most technological processes related to the production of BGIS's and MSB's, there is a typical dependence of the results of subsequent technological processes on preceding ones, along with the presence of a significant number of uncontrollable and unmonitorable factors (instability of the properties of the raw materials being sprayed on, the effect of environmental factors and so on); that is, any process has stochastic (having the nature of regular randomness) and purely random (noncalculable) components. Under such conditions an operator cannot conduct a technological process in a mode that is close to optimum, and in a number of cases this problem can be solved only by a control computer.

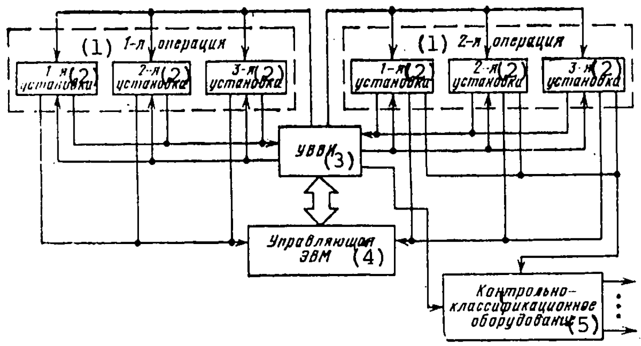

Figure 11.4. Block diagram of a system for the optimum control of a sequential technological process.

Key:
1. Operation No .
2. Unit No .
3. UVVI
4. Control computer
5. Monitoring and classification equipment

The basic function of the computer in an automated optimum control system is to perform, on the basis of measured values of the process's parameters and accepted mathematical methods (linear programming, regression and correlation analysis and others), a greater (in comparison with logic-program control) number of computations and to use the results of these computations to work out the controlling actions (advice to the operator). The design of ASUTP's provides for equipment-program communication between successive operations in the process (Figure 11.4) and the extensive use of methods for the statistical control of a process as a whole (see Section 10.2), it being the case that the use of an ASUTP with adaptation is most effective for many of the technological processes involved in the production of BGIS's.

In contrast to extreme control systems (without adaptation), where the optimum strategy is determined unambiguously (the distribution of probabilities for the random variables is assumed to be known), during operation an adaptive control system must recognize the nature of the random variables and, on the basis of the results of the analysis, work out some optimum strategy or another. What has been said is explained by Figure 11.5. From the figure it is obvious that the information entering the system's input is filtered (by either an equipment or program filter) in order to isolate information related to the effect on the process of uncontrollable and unmonitorable factors (noise). The results of the primary processing of the information, on the basis of a mathematical model, are used to predict the course of the process, as well as to calculate the optimum mode for its conduct. The data obtained are processed in a status analyzer. If the areas of technological process prediction and optimum process conduct mode do not intersect, control is transferred to a control process status analyzer that, through a correction unit, makes the necessary correction in the mathematical model in order to improve the quality of the control process. As soon as areas of prediction and optimum mode intersect, control is transferred to the unit that is working out the control actions.

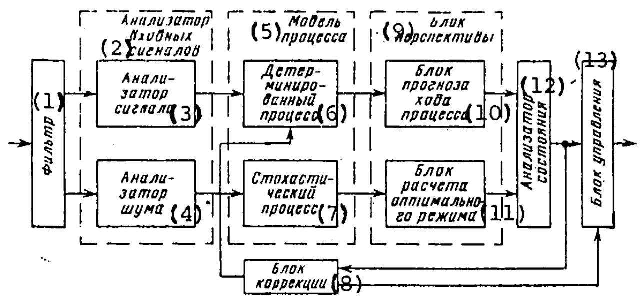

Figure 11.5. Block diagram of the information processing process in an adaptive control system.

Key:

1. Filter
2. Input signal analyzer
3. Signal analyzer
4. Noise analyzer
5. Process model
6. Deterministic process
7. Stochastic process
8. Correction unit
9. Prospects unit
10. Process course prediction unit
11. Optimum mode calculation unit
12. Status analyzer
13. Control unit

The diagram presented for the information processing process in adaptive systems corresponds to the case where the results of a passive experiment are used in the mathematical model. An adaptive control system's software can also include an active experiment unit that, through an experimental analyzer unit, makes the necessary correction in the mathematical model.

The third clas~ includes ASUTP's that monitor and control groups of processes or a single complex process within the framework of a production subunit (section, technological line). ASUTP's in this class are systems of an organizational-technological nature, which is determined by the purposes and problems involved in controlling an object.

A system for controlling a group of technological operations is also charged with organizational control problems that are aimed at reducing disorderliness in a given production process and optimizing the goods list distribution of the articles being produced in accordance with the portfolio of orders. In this case direct control of the technological process is subordinated to more general purposes and goals; that is, this type of control of technological processes is of the integrated type.

In the general case the structure of integrated control systems is a multilevel one (normally two or three hierarchical levels), it being the case that at least on the upper level, the basic link in the automated control system is man. Integrated control systems are formulated on the basis of ASUTP's from the first or second classes. Their introduction is becoming more and more important because they are component parts of the production control system as a whole and, therefore, carry out a definite, more generalized assignment in parallel with the solution of a specific technological process control problem.

According to the different classes of ASUTP's and the different versions of their block diagrams, the equipment facilities of ASUTP's can be divided into the

following four groups on the basis of their functional purpose:
facilities for processing information and solving technological process control problems (control computers);
facilities for direct interaction of the ASUTP with the technological equipment (sensors and actuating members);
facilities for transmitting and converting information from the sensors to the computer and vice versa;
facilities for the interaction of operating personnel with the system.

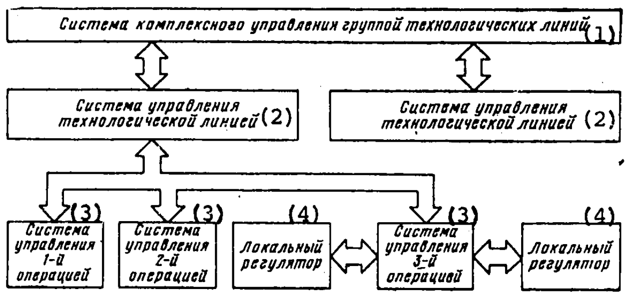

Figure 11.6. Generalized block diagram of an integrated ASUTP.

Key:
1. System for integrated control of a group of technological lines
2. Technological line control system
3. System for control of operation No .
4. Local regulator

ASUTP's in the second and (particularly) third classes have a complicated hierarchical structure (Figure 11.6) and consist of several computers: a central control computer and less powerful peripheral control computers that carry out the primary information processing and realize the special control algorithms.

In the general case, the complex of ASUTP equipment can consist of the following devices:
a central control computer with a priority program interrupt unit, selector and program-controlled channels, and devices for bilateral automatic exchanges with the upper-level computer(s) and the lower-level minicomputers that control the separate technological operations or processes;
an expanded complex of memory units, including large-capacity magnetic tape and disk storage units;
a complex of information input-output devices, primarily for digital single-bit and symbolic information, as well as analog-to-digital and digital-to-analog converters with channel commutators;
a central monitoring and control board with a mnemonic diagram of the controlled object, an information display (for both textual and graphic information), and a documentation unit;
local subsystems for the automatic monitoring and control of technological operations, with panels for the bilateral exchange of information with the central control computer, as well as visual depiction and documentation units;
communication line concentrators with commutators and analog-to-digital and digital-to-analog converters;
primary information sensors, including automatic analog and digital information sensors, as well as local consoles for the manual input and transmission of information;
actuating members.

A more detailed description of this hardware and its characteristics is given in [2,15]. The specifications of the control computers, minicomputers and microprocessor microcomputers are presented in Appendix 2.

11.2. AUTOMATED TECHNOLOGICAL PROCESS CONTROL SYSTEM FOR THE PRODUCTION OF THE PASSIVE PART OF THICK-FILM BGIS'S

Before describing the ASUTP for the production of the passive part of thick-film BGIS's, it is necessary to discuss the basic characteristics of this process as a controlled system. A diagram of the technological process involved in the production of thick-film BGIS's is presented in Figure 11.6. From the diagram it is obvious that the process consists of one group of preparatory and three groups of basic operations: manufacturing of the passive elements, monitoring-classification and assembly.

This process is characterized by a large number of technological operations, complexity and an abundance of various random effects; as a consequence, the process's reproducibility is comparatively low.

The group of operations for the production of the passive elements (preparation of the pastes, application and vzhiganiye of the conductors, dielectrics and resistors) determines the integral value of the thick-film technology.

The basic components of the conducting and resistive pastes are finely dispersed powders of precious metals, a special glass frit and a mixture of organic liquids. The paste is applied by an automatic UPM3.280.000 unit, which has the following specifications:

Number of simultaneously treatable cards	2
Number of four-position swivel tables	2
Paste application	double-sided
Operating cycle, s	3
Regulation of wiper's rate of motion	continuously adjustable
Leveling of paste in front of wiper	automatic
Card feed for charging	automatic

Vzhiganiye of the passive part of thick-film BGIS's is a complex process, for which a furnace of the SK-10(16.5)UP type, having five temperature zones, is used. In the first and second zones the organic components are eliminated from the paste, in the third and fourth an oxidation-reduction process takes place, and in the fifth the glass is sintered with the ceramic substrate, thus completing the process of the formation of the thick-film resistors.

An analysis of the distribution of reasons for rejection shows that the greatest percentage of rejection (37 percent) occurs during the inspection after the resistors undergo vzhiganiye, although the causes for the appearance of the defect actually build up during all the preceding operations and are determined by the quality of the preparation of the substrate, its dimensions, the shape and quality of the surface, the quality and uniformity of the resistive pastes' composition, the quality of the pattern, the application conditions and the temperature and temporal conditions of the vzhiganiye process. Thus, the percentage of output of serviceable BGIS's depends both on controllable and uncontrollable and random factors.

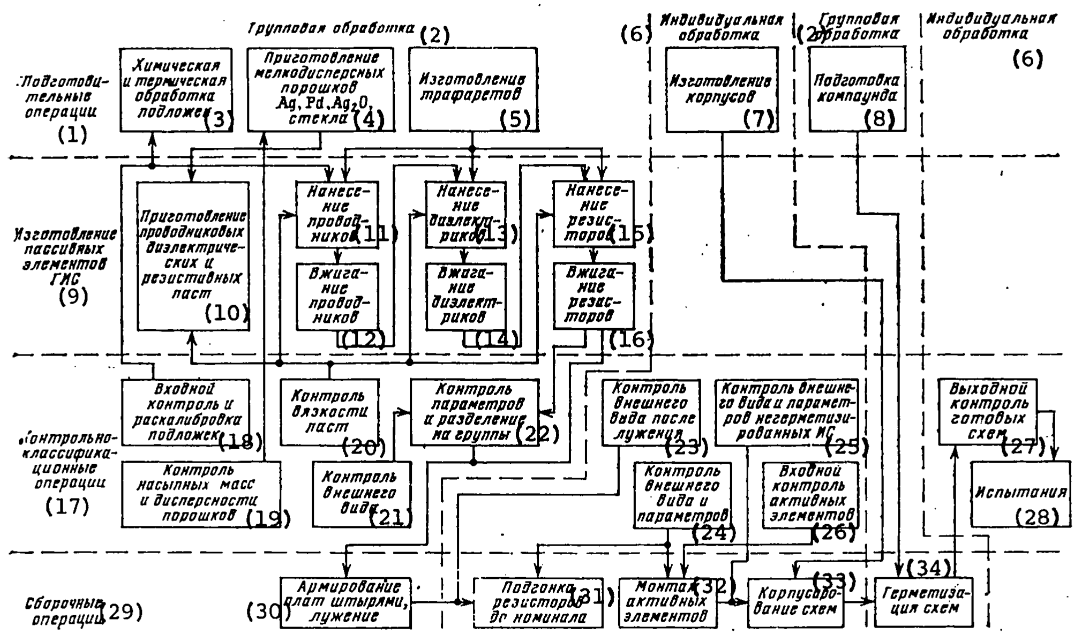

Figure 11.7. Diagram of technological process for the production of thick-film BGIS's.

Key:

1. Preparatory operations
2. Group treatment
3. Chemical and thermal treatment of substrates
4. Preparation of finely dispersed Ag, Pd, Ag_2O and glass powders
5. Production of patterns
6. Individual treatment
7. Production of bodies
8. Preparation of compound
9. Production of passive hybrid integrated circuits
10. Preparation of conducting dielectric and resistive pastes
11. Application of conductors
12. Vzhiganiye of conductors
13. Application of dielectrics
14. Vzhiganiye of dielectrics
15. Application of resistors
16. Vzhiganiye of resistors
17. Monitoring and classification operations
18. Input monitoring and calibration of substrates
19. Monitoring of poured masses and degree of dispersion of powders
20. Monitoring of viscosity of pastes
21. Monitoring of appearance
22. Monitoring of parameters and separation into groups
23. Monitoring of appearance after tinning
24. Monitoring of appearance and parameters
25. Monitoring of appearance and parameters of unsealed IS's
26. Input monitoring of active elements
27. Output monitor g of finished elements
28. Testing
29. Assembly operations
30. Reinforcement of cards with pins, tinning
31. Adjustment of resistors to rated values
32. Assembly of active elements
33. Enclosure of circuits
34. Sealing of circuits

With the help of a mathematical description of this complex process, models for the technological process involved in the production of the passive part of thick-film BGIS's have been obtained. For instance, by using screening experiments and the methods of prior ranking and random balance, the basic factors of the technological process that have the greatest effect on the reproducibility of the resistors were discovered. By realizing a fractional factorial experiment of the 2^{6-1} type (see Chapter 10), it is possible to obtain a mathematical model for the pastes used in thick-film resistors:

$$\hat{y}_{om} = 0.478 + 0.085x_1 + 0.053x_4 - 0.07x_5 - 0.012x_1x_5 - 0.012x_4x_5.$$

Using this mathematical model, it is possible to exercise control over the technological process for producing the passive part of thick-film BGIS's according to the rated value of the resistors' resistance.

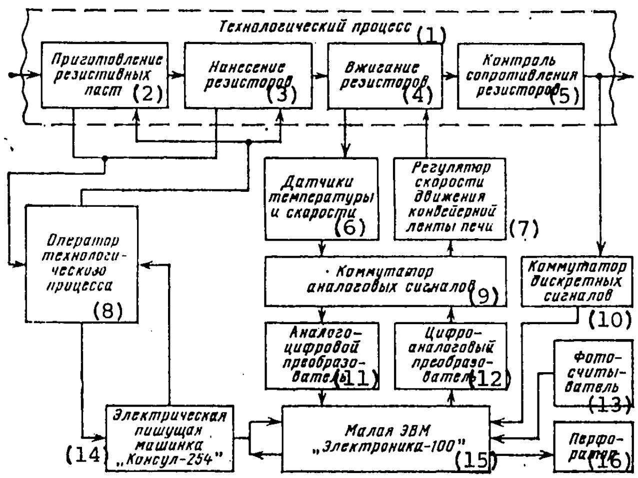

Figure 11.8. Block diagram of ASUTP for manufacturing the passive part of thick-film microcircuits.

Key:

1. Technological process
2. Preparation of resistive pastes
3. Application of resistors
4. Vzhiganiye of resistors
5. Monitoring of resistors' resistance
6. Temperature and speed sensors
7. Furnace conveyor belt speed regulator
8. Technological process operator
9. Analog signal commutator
10. Discrete signal commutator
11. Analog-to-digital converter
12. Digital-to-analog converter
13. Photoreader
14. "Konsul-254" electric typewriter
15. Small "Elektronika-100" computer
16. Perforator

Let us examine in more detail an ASUTP for manufacturing the passive part of thick-film microcircuits (Figure 11.8). This system realizes the following:

local control of the resistor vzhiganiye operation (on the control level);

control of the operations of preparing and applying the resistive pastes (on the information-advisory level);

operational monitoring and supervisory control of the production of the passive part of a BGIS;

automated statistical monitoring of the thick-film resistors' parameters.

As its main output parameter, the ASUTP uses the percentage of output of serviceable cards after the resistor vzhiganiye operation.

The ASUTP for the production of the passive part of thick-film BGIS's and MSB's is constructed according to a hierarchical principle. On the upper level of the system, analysis of the technological process is carried out and automated statistical monitoring according to the quality indicator--percentage of output of serviceable passive cards--is conducted. On the lower level there is automatic or manual (according to "advice" from the system) control of the technological modes in the basic operations [23].

The nature of the control is determined on the basis of an analysis of information about the results of the automated statistical monitoring, for the conduct of which the initial information is a data sample about the resistors' resistance after vzhiganiye that is obtained from an automatic resistance monitoring unit through a discrete channel commutator. The initial data are used to calculate the percentage of output of serviceable cards in the sample, the percentage of output of servicea- resistors according to their rated values, and the mean arithmetic values and root-mean-square deviations of the resistance of the resistors in the sample.

Sampling data accumulated over a week's time are used to calculate the average value of the output quality indicator and the lower monitoring alert boundary. The current value of the percentage of output of serviceable cards in a sample is compared with the value corresponding to the lower monitoring alert boundary, and when it is greater than the value of this boundary, there is a changeover to automatic control of the speed of the furnace's conveyor belt. However, if the percentage of output of serviceable cards in the sample is smaller than the lower monitoring alert limit, the sampling parameters are analyzed and the results of the analysis are used to change over either to automatic control of the furnace's conveyor belt's speed according to one of the rated values within the limits of the limitations on the technological vzhiganiye conditions or to the informational-advisory mode of controlling the resistor application and vzhiganiye operations. In this case, advisory information on the change in the technological vzhiganiye (temperature in the furnace's sintering zone) and paste application (change in the wiper's pressure, replacement of the pattern and so on) modes is printed out.

If the current value of the percentage of output of serviceable cards in a sample is below the allowable level, as determined by economic considerations, a recommendation for replacement of the resistive pastes is printed out. Correspondingly, information on the distribution of the resistances of the resistors in the sample is both printed and punched out; the technologist uses this information to make an operational analysis of the process. Information that has been accumulated from several samples is processed by statistical analysis programs in a "Minsk-22" computer.

The automatic mode utilizes a self-adjusting algorithm that constructs a mathematical model of the dependence of the resistors' resistances on the speed of the furnace's conveyor belt, with correction of the model's parameters according to the current values of the resistors' resistances, the conveyor belt's speed v and the temperature T in the furnace's sintering zone. Information on the temperature and speed are entered in the computer, from the appropriate sensors, through an analog channel commutator and an analog-to-code converter. The mathematical model for the vzhiganiye process is a second-order polynomial:

$$R = av^2 + bv + c \text{ when } T = \text{const.}$$

The model's coefficients a, b and c are computed as the result of the solution of a system of linear equations by Kramer's method. The constructed model's parameters are used to determine the correcting action Δv, which is transmitted through a code-to-analog converter and the analog channel commutator to the speed regulator, which changes the furnace's conveyor belt's speed.

Information on the state of the resistive pastes, the resistor application conditions and the planned quota and actual output of articles from the conductor and resistor application and vzhiganiye operations is entered in the computer through one of the recording devices (a manual input unit, an external UVVI, or the computer's keyboard register). The resultant control information for the current moment is printed as a table, with a periodicity determined by the technological cycle for the resistor vzhiganiye operation, and then transmitted to an information panel through an independent control board.

The system's hardware complex is based on an "Elektronika-100" computer. In addition, the system contains the following equipment:
four temperature sensors, having a measurement range of 250-760°C with sensitivity of 100 μV/deg;
a speed sensor that converts the furnace's conveyor belt's speed into an analog signal (1-5 V); the measurement limits are 15-150 mm/min with a sensitivity of 0.5 V·min/mm;
a speed regulator that controls the actuating mechanism that changes the furnace's conveyor belt's speed within limits of 30-100 mm/min;
automatic resistance monitoring units that convert a resistor's resistance into a discrete signal with 0.3-percent accuracy; the measurable resistance range is 1 Ω to 10 mΩ;
an automatic card feed and resistor-contact unit that feeds the cards in and sorts them into three groups; the unit's productivity is 1,600 pieces/h;
an information panel with an independent control board, for the depiction of production information.

The system's software includes: program modules for entering the resistors' resistances, the conveyor belt's speed and the furnace's temperature in the computer; subprograms for computing the percentage of output and quantity of serviceable cards, as well as the mean arithmetic value of the resistors' resistances, and analyzing the technological parameters, computing the change in the conveyor belt's speed, forming the voltage code according to the computed value of the change in speed, generating the correcting signal and sending it to the speed regulator, and computing the root-mean-square deviation; a control program; supervisory information input programs for the automated statistical monitoring program; supervisory information printing programs and a series of standard programs for the "Elektronika-100" computer, such a translation from the decimal to the binary system, multiplication, division and so on.

By making it possible to achieve the optimum change in the temperature conditions for vzhiganiye and automatically correct the furnace's conveyor belt's speed, the introduction of this system into the production process increases the output of serviceable cards with resistors by more than 10 percent and the productivity of the technological process by more than 40 percent [23].

APPENDIX 1. SPECIFICATIONS OF DEVICES FOR PRODUCING TECHNICAL DOCUMENTATION AND INDUSTRIAL EQUIPMENT

YeS7033 Alphanumeric Printer (for the output of textual documentation on paper)

Printing speed, lines/min.	1,100 or 550
Printing density, lines/cm	2.4, 3.2
Number of symbols per line	120, 128, 160
Size of symbols, mm.	2.4 x 1.4
Capacity of buffer memory, bytes	160
Power consumption, kW.	3.5
Operating conditions, °C	5-40
Dimensions, mm	1,250 x 820 x 1,270
Weight, kg	700

YeS7051 and AP-7251 Graphic Plotting-Board Recorders (for the automatic drawing of graphs, diagrams, drawings and functional and electrical diagrams)
The YeS7051 unit works with YeS-series computers or the FS-1501 photoreading device.
The AP-7251 unit works with ARM computers (ASVT-M or SM computers) or from an AP-5080 NML [magnetic tape storage] or from an FS-1501.

Technical Parameters	YeS7051	AP-7251
Working field, mm	1,000 x 1,050	1,189 x 841
Minimum spacing, mm	0.05, 0.025	0.05, 0.025
Maximum drawing speed, mm/s	50	100 or 50
Number of types of lines	3	3
Width of lines, mm	0.3, 0.6, 0.8	0.3, 0.6, 0.8
Number of drawable symbols	Up to 255	---
Number of angles of symbol inclination	16	---
Number of scales or symbol dimensions	3	---
Repetition, mm	___	± 0.1

YeS7052 and AP-7252 Drum-Type Graphic Recorders (for the automatic drawing of graphs, diagrams, drawings, small-format drawings and functional and electrical diagrams)
The YeS7502 works with YeS-series computers, an FS-1501 photoreading device and YeS computer NML's.
The AP-7052 works with ARM computers (ASVT-M or SM computers), the FS-1501 photoreading device and the AP-5080 NML.

Technical Parameters	YeS7052	AP-7252
Working field, mm	600 x 380	594 x 420
Minimum spacing, mm	0.1, 0.05	0.05, 0.025
Maximum drawing speed, mm/s	100	250, 100
Number of types of lines	3	3
Width of lines, mm	0.3, 0.5, 0.8	0.3, 0.6, 0.8
Number of drawable symbole	65	---
Symbol dimensions, mm	3.0, 6.0, 12 or 1.5, 3.0, 6	---
Repetition, mm	---	± 0.2

KPA-1200 Koordinatograf With Program Control (for programmed drawing of any outlines approximating straight lines, arcs of circles and parabolas)

This koordinatograf is used to perform the following operations:

four-color drawing on paper, with an automatic change of colors, with curve-drawing instrument;

cutting enamel with a cutter having tangential control;

engraving on enamel or metal;

producing phototemplates by drawing with a light beam directly on the emulsion layer of a photographic material.

When operating with the photographic head, the koordinatograf's working field is shielded from light.

Working area of the coordinate table, mm	1,200 x 1,200
Maximum straight line drawing rate, mm/s	90
Positioning accuracy, mm	0.05
Number of replaceable diaphragms	24
Maximum size of printed element, mm:	
on 1:1 scale	11 x 18
on 1:2 scale	5 x 8
Width of lines, mm	0.1-5.0
Drawing scales	1:100, 1:50, 1:20, 1:10, 1:5, 1:2, 1:1, 2:1, 4:1, 5:1, 10:1, 20:1, 50:1, 100:1

EM-538 Precision Photokoordinatograf (for producing phototemplates of multilayer printed-circuit cards and microassemblies by the method of generating an image on photographic film with the help of a modulatable light ray)

Structurally, this photokoordinatograf is a two-coordinate table with independent movement with respect to the x and y coordinates. Step motors are used for the drive. The table's upper plate, to which a vacuum cassette with the photographic film is attached (emulsion layer downward) moves along the x axis. Inside the pedestal is a carriage with a photographic head that moves along the y axis. The carriage with the photographic head, which has an illuminating system, a high-resolution lens and a symbol-changing mechanism that is a diaphragm with 93 elements, is used to obtain lines of different widths, contact areas and alphanumeric information.

Maximum size of working field, mm	450 x 450
Discreteness of movement, mm	0.020
Positioning error, mm:	
of printing assembly elements	±0.03
of literal and digital information	±0.05
Maximum size of symbols, mm	5
Maximum size of printable fragments, mm	25
Number of diaphragms in photographic head	93
Width of lines, mm	0.1-2.5
Maximum rate of movement, mm/s	67

APPENDIX 2. SPECIFICATIONS OF MICROCOMPUTERS FOR ASUTP'S [61]

Elektronika S5-01

This multicard, general-purpose microcomputer consists of the following modules: microprocessor, operational and permanent memories, memory control and central input-output control. It has a developed input-output system that contains a variable set of modules: parallel interface, an interrupt and timer module for organizing the microcomputer's functioning on a real time scale, and a module for controlling telegraph equipment, devices for information input-output on punched tape, a typewriter, an analog-to-digital converter, and devices for communicating over telephone and telegraph links.

Operation speed, thousands of operations/s	10
Number of basic commands	31
Word length, bits	16
Memory capacity, Kbytes	28
Interrupt system	three-level
Interrupt depth	8
Operating temperature, °C	-10 to +50
Power consumption, V·A	90
Dimensions, mm	420 x 380 x 225

Software: a dispatch system, peripheral gear controllers, library of standard microprograms, library of standard subprograms, monitoring and diagnostic tests, assembler and loader for symbol-encoding language, modeling programs.

This microcomputer is used in data transmission systems, small and medium-sized ASUTP's to control equipment and industrial installations, control and measuring systems, and automated testers, trainers, simulators and information collection and processing systems.

Elektronika S5-02

This is a modified model of the "Elektronika S5-01" microcomputer that has a more developed input-output system for controlling an extensive set of peripheral gear.

Elektronika S5-11

A single-card, general-purpose control microcomputer that contains three basic units connected by a single 16-bit main information line: microprocessor, input-output unit, memory.

Microprocessor: arithmetic-logic unit, microprogram control unit.

Input-Output Unit: central control unit, communication links.

Memory: operational and permanent memories.

Control principle	Microprogrammed
Operating principle	Parallel
Operating speed, thousands of operations/s	10
Word length, bits	16
Number of basic commands	31
Memory capacity, bits:	
operational memory	128 x 16
permanent memory	1,024 x 16
Memory capacity enlargement capability, Kbytes	Up to 64
Input-output	four 8-bit digital inputs, four 8-bit digital outputs
Working temperature , °C	-10 to +50
Power consumption, V·A	10
Dimensions, mm	267 x 270 x 28.5
Weight, kg	1.2

This computer is used in programmed subscriber points, channel-switching equipment, automated large-scale integrated circuit monitoring systems, design-testing systems, telemechanical and industrial automation systems, microphotocomposition units for the electronics industry and so on.

In order to change the area of application of this microcomputer, it is sufficient to replace only two large-scale integrated circuits.

Elektronika S5-21

A single-card microcomputer that is program-compatible with the "Elektronika S5-01" microcomputer. Structurally, it is based on a single printed-circuit card that holds a microprocessor, the operational and permanent memories and the input-output channels.

The input-output system includes four reorganizable 8-bit digital channels and two sequential 8-bit digital channels. There is a capability for receiving information over eight priority-interrupt channels and asynchronous operation with an external memory. The frequency stability network is 600, 100, 60, 12 and 10.1 kHz and 1 Hz. This microcomputer is intended for use in systems operating on a real time scale.

Operating speed, thousands of operations/s	150-200
Word length, bits	16
Memory capacity:	
operational memory, bits	256 x 16
permanent memory, Kbytes	2 x 16
Memory capacity enlargement capability, Kwords	Up to 32
Number of basic commands	31
Working temperature, °C	-10 to +50
Power consumption, V·A	20
Dimensions, mm	240 x 180 x 30

Used in monitoring-measuring and control equipment, communication links, terminal units and so forth.

Kristall-60

A microcomputer based on a K580IK80 microprocessor large-scale integrated circuit and a K505RU6 operational memory large-scale integrated circuit.

Operating speed, thousands of operations/s	Up to 500
Word length, bits	8
Memory capacity, Kbits	Up to 64
Number of commands	78
Number of priority-interrupt levels	8

Peripheral Gear Complex: "Konsul-260.1" electric typewriter, FS-1501 photoreading unit, PL-150 perforator.

Peripheral Gear Complex Enlargement Capability: up to 256 input units and 256 output units.

Software: cross-assembler, interpreter, emulyator [translation unknown], macro-assembler, monitor.

Used in measuring devices, automated systems for monitoring and controlling technological processes and industrial installations, information-measuring and testing systems, scientific experiment automation systems.

Elektronika NTs-03

This microprocessor microcomputer consists of the following modules:

PRTs1, PRTs 2--processors,

PU1, PU2--modules for interaction with control console,

AT--module for servicing inquiries on use of common main line,
UM--interface amplifier-matcher,
OZU--operational memory module with capacity of 2K, 4K, 8K words,
KK--"Konsul-260" electric typewriter control controller,
KSP--PL-150 perforator and FS-1501 photoreader control controller,
PVV--"Videoton-340" display control controller,
VV--programmable interface,
BP--power unit,
PPU--console.

Processor

Word length, bits	16
Operating speed, thousands of operations/s:	
register-register type:	
in single-processor version	100
in two-processor version	160
register-memory type:	
in single-processor version	50
in two-processor version	80
Number of commands differentiable by operations code and form of addressing	190
Number of priority-interrupt levels	8
Interrupt reaction time, μs	25
Number of user registers	4

Memory Module

Volume, Kbytes	32
Volume when additional modules connected, Kbytes	128
Program scope	short, relative, direct, through register, stack
Data scope	short in zero page, direct, through register with increment and decrement, with indexing
Interface compatible with interface of SM series computers; exchange operating speed	100,000 words

Software: cross-system of programming realized on a BESM-6 large digital computer; assembler, debugging system, text editor, library of standard programs, monitoring system, punched tape operating system.

The following operations are carried out from the programming engineer's console: power connection and disconnection, direct access to memory in readout and entry modes, readout with display of processor registers, command-by-command execution of programs, halting of automatic execution of programs, memory cell display according to a selected address in the automatic operation mode, initial setting of computer modules, suppression of key actions.

There exist additional capabilities for organizing multiprocessor and multicomputer complexes; complexes interacting at the common main line interface; the connection of additional memory units; the connection of additional specialized units.

General Data

Power consumption, V·A	30
Dimensions, mm	483 x 360 x 221
Weight, kg	28

This microcomputer is used in systems for controlling technological processes and measuring and monitoring-testing equipment, for the collection and preliminary processing of data in information retrieval complexes, to solve engineering computational problems, and as a peripheral, programmable terminal controller in computer complexes.

CONCLUSION

In order to acquaint the reader with the prospects for the further development of microelectronics and radio equipment in the next decade and the problems for the solution of which the future engineer specializing in the design and production of REA must be prepared, let us discuss several prognostic evaluations of the development of microelectronics and MEA based on it.

Microelectronics will continue to be developed at a rapid rate. It is assumed [11, 18,25] that the rate of growth of the degree of integration of IS's will even increase and that the functional complexity will triple each year. Along with the improvement and expansion of production of IS's, there will be created complex solid-state electronic instruments that perform the functions of units, devices and equipment as a whole. Primary development will be maintained for discrete microelectronics; that is, the increase in the degree of integration will take place because of a reduction in the size of the transistors, diodes and resistors used in an IS realized inside a silicon monocrystal. At the present time, however, the possibilities of light photolithography can be regarded as exhausted. Therefore, for a further reduction in the size of IS elements, to $(50\text{-}100)\cdot 10^{-4}$ µm, in the next decade we must see the industrial mastery of new technological methods for forming structures on the basis of the utilization of electron-beam and X-ray lithography, ion implantation and ion doping.

In connection with the increase in the functional complexity of IS's and the requirements for improving their quality as well as the efficiency and accuracy of the manufacturing process, in the next 10 years we must realize complete automation of the processes involved in designing and producing IS's.

The acceleration of the rate of scientific and technical progress in radioelectronics has resulted in a continuous increase in the complexity of MEA. At the present time the complexity of some devices has reached 10^8 elements and is continuing to grow. Under these conditions, a most important national economic goal is the utmost possible improvement in the quality and reliability of MEA and the improvment of the efficiency of its production. The successful solution of these problems is possible only with full automation of the designing and production of MEA on the basis of the utilization of computers.

This problem is complicated and multifaceted. For total automation of the designing of MEA it is necessary, for example, to develop new and more accurate methods for computer calculation and modeling of the quality characteristics of the MEA being designed, in order to replace laborious experimental investigations of these characteristics. Further refinement is needed in the methodological questions related to the creation of automated systems for technological preparation for production, the automation of technological processes and so on.

Thus, in radio- and microelectronics in the next decade, considerable attention will be devoted to questions of automating the designing and production of IS's and MEA.

Both domestic and foreign work experience in this area shows that an engineer concerned with automation problems must be a highly qualified specialist both in the area of designing and producing MEA and the area of computer technology and programming. Only when this is the case will the greatest effect in the solution of automation problems be achieved.

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SOFTWARE

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PROCESSING OF RASTER IMAGES OF EXTENDED OBJECTS: PATTERN RECOGNITION

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 6, Nov-Dec 81 (manuscript received 19 Nov 79) pp 63-65

[Article by A. G. Vostretsov, V. I. Kushnir and A. N. Yakovlev]

[Text] Discussed in this work is the problem of automatic detection of the image of a parallelogram. This problem occurs, for example, during the search for and recognition of extended objects of simple geomteric forms (bars of cylinders, prisms, etc.) by using side-looking sonar systems with a raster image of the space being investigated [1]. If the object of the search is located on an underlying surface, the useful signal has to be picked out of the background of reflections from this surface. Since the levels of reflections from the object and the underlying surface are different, this isolation can be performed by threshold processing of preliminarily filtered realizations. As a result, in each realization the information of interest to us is a logical voltage (chord) convenient for further digital processing. The aggregate of realizations will make up a raster two-shaded image of the surface being sounded (see fig. 1). With this method of signal isolation, noise chords caused by the statistical nature of the signals being received will also appear in the raster in addition to the useful chords belonging to the objects.

To solve the final problem of automatic recognition of the objects, it is necessary to generate the set of chords in the raster that make up the images of the individual objects. A feature that indicates the chords belong to individual objects is their connectivity [2]. This condition can be expressed the following way: $x_{ie} > x_{(i+1)b} \wedge X_{(i+1)e} > X_{ib}$, where X_{ib} and X_{ie} are the coordinates of the beginning and the end of the chord in the i-th line, and $X_{(i+1)b}$ and $X_{(i+1)e}$ are the same in the (i+1)-th line. This algorithm allows effecting selection of objects in real time, i.e. at the rate the information comes in [3].

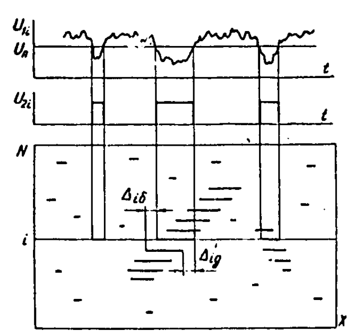

Fig. 1. Raster image of surface being sounded

After selection of the chords belonging to individual objects, the problem of isolating the parallelogram image from them is solved. When there is no noise, the latter is the aggregate of connected chrods, the ends of which lie on straight and parallel lines called bounds.

To meet the condition of rectilinearity and parallelism, it is necessary and sufficient that the antioverlaps Δ_i of the chords at the corresponding bounds be equal between themselves and coincide in sign. In the process, the "+" sign is assigned to the antioverlap of two neighboring chords, when the "X" coordinate of the next chord is greater than that for the preceding, and the "-" in the opposite case.

In real conditions, since the image bounds are distorted by noise, precise equality of antioverlaps between themselves is not possible. Therefore, there arises the question of statistical decision-making on the presence of an object.

The algorithm for making a decision on the detection of a parallelogram consists in checking for the simultaneous meeting of the following conditions:

$$|\bar{\Delta}_б-\bar{\Delta}_л|<\alpha \text{ —} \qquad (1)$$

the condition of parallelism, and

$$\frac{1}{n}\sum_{i=1}^{n}(|\Delta_{iб}-\bar{\Delta}_б|+|\Delta_{iл}-\bar{\Delta}_л|)<\tau \text{ —} \qquad (2)$$

the condition of rectilinearity of the bounds. Here $\bar{\Delta}_б=\frac{1}{n}\sum_{i=1}^{n}\Delta_{iб}$, $\bar{\Delta}_л=\frac{1}{n}\sum_{i=1}^{n}\Delta_{iл}$ are competent estimates of the quantities, and $n_2<n<n_1$, where n_1 and n_2 are constants defined by the extent of the objects of the search. The thresholds α and τ are selected based on the specified probability for parallelogram detection.

Algorithm characteristics and the thresholds α and τ were found by using the computer simulation method. As can be seen, the algorithm requires few computations. Therefore, it can be implemented on the base of a microcomputer or specialized microprocessor system [4].

Fig. 2 shows the structure of a device suggested for implementing the algorithm described.

Filtration and single-threshold processing of the source signal occur in the initial processing unit (BPO). The chords are analyzed for overlap by using the shift register (SR), which effects a delay of a line of the image for the period of a line scan, and the AND circuit (&). Upon a signal from the AND

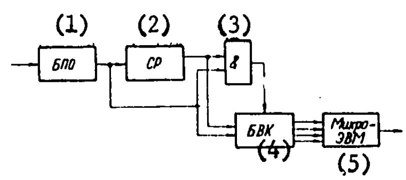

Fig. 2. Structural diagram of recognition device

Key:
1. BPO [initial processing unit]
2. SR [shift register]
3. & [AND circuit]
4. BVK [coordinate output unit]
5. microcomputer

circuit, the coordinate output unit (BVK) records the coordinates of the beginning and end of the chords in the current and delayed lines X_{b1}, X_{b2}, X_{e1} and X_{e2} respectively. The images are processed further by using a specialized microcomputer in real time provided that in each line there can be chords belonging to no more than 10 objects. To implement non-frame processing of an image, the need for which occurs in operating with side-looking sonars, storage is allocated as follows.

Allocated first in main storage is a region in which the coordinates of the beginning and end of all chords that caused actuation of the AND circuit are recorded (see fig. 2). The address of the beginning of this region is designated BEC, and the coordinates are stored in this region in accordance with fig. 3. The absence of an object is denoted by zeros. As each new line comes in, the old contents are deleted from the region and the new recorded. Since each time we record in storage the chord coordinates from the current and delayed lines, then for the two successive records of chord coordinates belonging to an object, the coordinates X_{b1} and X_{b2} will match. This fact will be used in selecting the object in the raster.

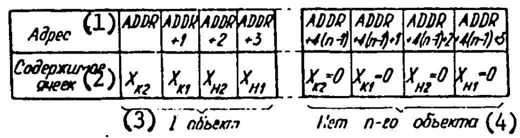

Fig. 3. Record of chord coordinates in microcomputer storage

Key:
1. address
2. contents of cells
3. one object
4. no object

K2, K1 = e2, e1 [end]
H2, H1 = b2, b1 [beginning]

Allocated in storage for each isolated object is a region to store the values of the increments of the corrdinates at the end and beginning of the chords, the number of these increments and the value of the coordinate X_{b2} in the current line (for object identification). We use 10 of these regions. The coordinate of the beginning of the file of these regions is designated by BEGIN. Indirect addressing is used for efficient use of these storage regions. Used in the process are a pair of microprocessor registers D and E and a region in storage, the beginning address of which is designated by ADDR. Entered in the initial state in the ADDR region serially are the addresses of the corresponding objects of the storage regions, and the pair of registers D and E always point to the cells of the ADDR region in which the address of the first cell of the BEGIN region where there is no object is contained. Thus, kept in the ADDR region before the cell with the address indicated by registers D and E are the addresses of the cells from the BEGIN region occupied by objects , and the free cells come after it. After completion of processing, its address in the ADDR region changes places with the last processed object, and the D and E registers begin pointing to this freed region. Thus, the BEGIN region must contain the number of cells needed to service the maximum number of objects in a line (we use 10).

The automatic image processor is operated as follows. First, the coordinate values are entered into the BEC storage region. Then a check is made for objects in the preceding lines by comparing the first free region (D and E registers) with the ADDR address. An inequality indicates the presence of objects in the preceding lines. Then comes selection of chords: picking out the chords belonging to objects by the feature of matches between the coordinates X_{b1} from the BEC region and X_{b2} from the BEGIN region. If these chords are not found for some object, this means it has terminated, and the recognition program is switched on for it (inequalities (1) and (2) are checked). Then the chords belonging to the new objects are recorded and the cycle starts again.

This selection and recognition system was tested on a model of signals input into a microcomputer with 512 bytes of read-only memory and 256 bytes of main storage.

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DESIGN OF EXPERIMENTS FOR NONLINEAR ESTIMATION AND PATTERN RECOGNITION PROBLEMS

Moscow PLANIROVANIYE EKSPERIMENTA V ZADACHAKH NELINEYNOGO OTSENIVANIYA I RASPOZNAVANIYA OBRAZOV in Russian 1981 (signed to press 8 Jul 81) pp 2-4, 161-163, 169

[Annotation, table of contents, introduction and appendix from book "Design of Experiments for Nonlinear Estimation and Pattern Recognition Problems", by German Karlovich Krug, Viktor Aleksandrovich Kabanov, Gennadiy Aleksandrovich Fomin and Yevgeniya Sergeyevna Fomina, USSR Academy of Sciences, Scientific Council on the Complex Problem of Cybernetics, Order of Lenin Institute of Control Problems (Automatic and Remote Control), Izdatel'stvo "Nauka", 3650 copies, 169 pages]

[Text] This book deals with estimation of parameters that nonlinearly enter into the mathematical model of the object being studied. The close relationship between the problems of nonlinear estimation and pattern recognition is shown. Methods of design of regressive model parameter estimates and classifying rules are given. Methods of design of apriori and serial designs of experiments and a procedure for implementing them are discussed. This book is intended for a broad range of specialists engaged in development and use of software for statistical data processing and automation of experimental research. There are 5 tables, 30 figures, and a bibliography with 138 titles.

Contents

Introduction

At the contemporary stage of evolution of basic and applied research, ever greater importance is being assumed by its effectiveness both from the viewpoint of validity and soundness of decisions being made and from that of costs and time for conducting it. Among the means for achieving these aims, a prominent place is held by the mathematical theory of experiments. While earlier the field of application of this theory was limited largely to problems of combinatorial and extremal design of experiments, this field has now been expanded considerably. A major role here has been played by computers, for which it has been possible on the basis of numerical methods to develop optimal algorithms for estimation and design of experiments.

This work, a logical continuation of the monograph, "Design of Experiments for Identification and Extrapolation Problems," [34] deals with a systematic examination of methods of experimental design for two new problems: nonlinear estimation and pattern recognition.

The nonlinear estimation problem occurs in constructing complex mathematical models, nonlinear relative to the parameters being estimated, that describe physical and chemical mechanisms of the processes and phenomena under investigation. The problem is solved under the conditions of the effect in the general case of nonadditive, non-Gaussian, non-white noise. Such models afford fine prediction properties over a wider range of variation of input variables with a fewer number of estimated parameters than the polynomial regression models do.

Nonlinear models are finding ever greater application not only in scientific research, bot also in setting up automated process control systems. A brief survey or the numerous works accomplished in this field is given in this book. Special attention is paid to the problem, important from the practical viewpoint, of studying the capability of applying a priori synthesized optimal experimental designs that are more convenient than sequentially computed and implemented designs. We consider optimal algorithms for designing experiments in nonlinear estimation by using the methods of least squares and maximum likelihood and with the Bayes' approach.

The second problem involves the situation when the output variable has a fundamentally qualitative nature. In contrast to traditional statements of pattern recognition and classification problems, considered in this book is the case when the researcher-experimenter has the opportunity of controlling the source statistical material (training sample) and in this sense, designing the experiments.

The problem is considered in two aspects: statistical and determinist. It is shown that in the first case, the problem can be reduced to a partial statement of nonlinear estimation. The most promising objects of application of the algorithms developed here are automated systems for quality control of mass production. The determinist approach to design of the separating surface, particularly sequential design of experiments in refining the estimates of parameters of this surface, is very effective in computer-aided design of complex systems and the study of the regions of factor space in which the specified properties of these systems are afforded.

It should be noted that all the algorithms given in this book for estimation and design of experiments have been implemented as computer programs and registered in the USSR State Library of Algorithms and Programs. They have also been tested in a large number of model problems and successfully adopted in industry.

This book is intended for the continually growing number of specialists and researchers mastering modern mathematical models and facilities of computer technology.

Appendix. Algorithms for Design of Experiments and Solving Nonlinear Estimation and Pattern Recognition Problems

Given below is a brief list of programs for solving nonlinear estimation and pattern recognition problems. Detailed descriptions of the programs can be obtained from the USSR State Library of Algorithms and Programs by the registration numbers indicated below.

P001982. Program for refining parameters of nonlinear mathematical model by Marquardt method. Fomina, Ye. S. and Koslova, G. A. In: ALGORITMY I PROGRAMMY, No 1, 1977. Estimates of parameters of nonlinear multiresponse mathematical model are computed by nonlinear method of least squares (Marquardt numerical procedure). Program was written in ALGOL-60 for the TA-1M translator and checked out for the BESM-4. Similar programs are available in FORTRAN-4 and PL/1 for YeS DOS.

P001983. Program for refining parameters of nonlinear mathematical model by spiral method (Jones method). Fomina, Ye. S. and Koslova, G. A. In: ALGORITMY I PROGRAMMY, No 1, 1977. Implemented in the program is an efficient computational procedure for estimating parameters of nonlinear single-response regression model. Program checked out in ALGOL-60 (TA-1M translator, BESM-4).

P001669. Program for sequential design of experiments for multiresponse nonlinearly parametrized models. Fomina, Ye. S. In: ALGORITMY I PROGRAMMY, No 2, 1976. Optimal conditions for performing one or more experiments at some stage of sequential design are selected in accordance with the criterion of D-optimality of design. Design is searched for in region of factor space specified by limits in form of inequalities. An ALGOL-60 program (TA-1M translator, BESM-4).

P003155. Program for sequential design of experiments in case of nonlinear parametrization of multiresponse models. Fomina, Ye. S. and Koslova, G. A. 1978. An improved version of program P001669 in PL/1 for DOS of Unified System of Computers.

P001794. Sequential Bayes estimation of parameters of nonlinear models. Kabanov, V. A. and Repnikova, G. M. In: ALGORITMY I PROGRAMMY, No 3, 1976. Program is designed to estimate parameters, nonlinearly entering into model, with non-Gaussian errors of observation. Used to compute estimates is a recurrent procedure for calculation of multidimensional integrals by Monte-Carlo method. An ALGOL-60 program (TA-1M translator, BESM-4).

P001795. Bayes interval estimation of parameters of regression models. Kabanov, V. A. and Tokareva, V. N. In: ALGORITMY I PROGRAMMY, No 3, 1976. Interval estimates of parameters of density of probability of observed random quantities and regression models with nonlinear parametrization and non-Gaussian errors of observation are computed by using Bayes method with application of Monte-Carlo method for computation of multidimensional integrals. ALGOL-60 (TA-1M translator, BESM-4).

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P003241. Program for sequential optimal design of experiments with estimation of parameters of qualitative response function. Fomin, G. A. 1978. In accordance with the criterion of D-optimality, the program allows selecting conditions of a specified number of experiments at a certain stage of sequential design with refinement of the approximation of the response function in a neighborhood of specified level α. When necessary, the program can be used to obtain a local-optimal experiment design. Program is similar to P003242 in its characteristics. A PL/1 program for YeS DOS.

These programs have been tested in solving a number of practical problems.

The algorithms for nonlinear estimation and pattern recognition have also been included in the "DIPLEX" and "PLANEKS" software systems developed at the Problem Laboratory of Automatic and Remote Control, Moscow Power Engineering Institute (Order of Lenin).

The "PLANEKS" applications program package (PPP) is intended for calculating experiment designs and statistical processing of observation data in scientific and industrial research. The package modules afford an efficient solution to problems associated with building models of objects from experimental data and encompass all basic stages of research: 1) test of statistical hypothesis, study of laws of distribution of random quantities, analysis of measurement data; 2) estimation of parameters of a mathematical model of specified structure and statistical analysis of estimation results; 3) optimal design of an experiment for achieving the model properties desired.

The "PLANEKS" package is oriented primarily to research permitting control of the conditions for performing experiments (active experiment). At the same time, mathematical model parameter estimates can also be computed from data on observations on the object under investigation.

The package can be used to select the best model, estimate the parameters entering linearly and nonlinearly into a regression model and perform discriminant analysis of data.

"PLANEKS" package users do not have to have programming skills. Simplicity and convenience of package application are achieved by writing the specifications for computations in rather free nonalgorithmic form in a problem-oriented language (POYa) close to the natural language of the subject area.

The "PLANEKS" package can be applied by users with a varying degree of knwoledge on methods of experiment design and statistical data processing. The package control program includes blocks enabling problem solution even there is no explicit indication of the required algorithm for computations in the specification. In this case, the computational scheme is selected either from available source data or based on user responses to questions in a special questionnaire. The package is also an effective means for training users in the methodology of a given subject area. Included in it for this is a subsystem for analysis of the input job that enables detection of errors and recognition of the type of problem, as well as output of indications of source data missing in the specification that is needed for application of a particular computational scheme. By using simple instructions in the POYa, package users are given the capability of modifying computational schemes by changing the algorithms for searching for the extremum of a function, criteria of optimality of designs, type of design area, type of model of the research object, etc.

By using the design subsystem, users can extend the package by connecting to it their own problem programs and use them in the library mode.

The "PLANEKS" package structure permits rather simple modification and expansion of the subject field by including in it new algorithms and expanding the terminology of the problem-oriented language.

The package is built on the modular principle and includes over 100 modules.

The package has been implemented for the Unified System of Computers within the bounds of the YeS DOS operating system (version 2.1). For normal operation, 128K bytes of main storage are required. The software modules have been checked out in PL/1.

The interactive "DIPLEX" software system is intended for experiment design and processing of observation data in systems for automation of scientific research based on the SM-3, SM-4 and M-6000 computers with at least 24K bytes of main storage. The system does not require the user to program problems and can perform the functions of a consultant on statement of research problems and application of programs included in its library. Included in the "DIPLEX" system is the program for nonlinear estimation by the Marquardt method (similar to P001982) and sequential design of experiments with refinement of model parameters (similar to P003155).

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APPLICATIONS

UDC 551.46:681.3:53.08

INTEGRATED SYSTEMS FOR AUTOMATION OF SCIENTIFIC RESEARCH ON MULTIPURPOSE RESEARCH VESSELS

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 6, Nov-Dec 81 (manuscript received 17 Nov 80) pp 72-80

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[Text] Successful resolution of the problems associated with the study and rational use of ocean resources would be impossible without making use of the most modern hardware for automated experimental data acquisition, processing, storage, retrieval and presentation in a form convenient for research. The systems approach to the study of the physical fields of the ocean and their interrelation, typical of modern oceanology, the extension of the time and spatial scales of research and the intensification of use of specially equipped scientific research vessels (NIS) lead to the need for acquiring and processing large amounts of data. Processing of oceanologic information obtained on trips is now inconceivable without extensive application of electronics and computers combined into a system for automation of scientific research (SANI). A basic feature of these systems is that their platform is a scientific research vessel equipped with complexes of instruments for performing multidimensional ocean research. As a rule, instruments are placed in shipborne scientific laboratories when they are pertinent to an experiment. The specific nature of operation of a scientific research vessel may be determined by the need of performing scientific experiments in various fields of ocean science. By radio channels (including satellite), a shipborne SANI can be linked to communication processors of ground networks, performing in this case functions of a node of a computer system [1]. Such communication provides the capability of exchanging with shore computers information concerning the current trip or preceding research.

The task of automating research performed by multipurpose scientific research ships is complicated by such factors as the diversity of the physical quantities to be measured and their characteristics, the presence of a considerable number of methods for measuring the various physical quantities, the nonuniform procedures for recording data when using deck, towed and sounding apparatus, the need for collecting data from large areas over a long time period in a wide range of studies, the uniqueness of individual studies, the diversity of algorithms for recording and processing the data obtained, as well as the need for rapid configuration of the structure of the scientific research automation system in accordance with the requirements of new experiments, enhanced demands on system reliability, etc.

The data recorded both during the trip and after its completion must be accessible and understandable not only to those who directly organized the performance of a given experiment, but also to a broader range of users.

Let us consider the structure and design principles of the scientific research automation system for multipurpose scientific research vessels using as an example the integrated system for automation of scientific research under development for the "Akademik Mstislav Keldysh" scientific research ship, being constructed at the "Khollming" a/o [joint-stock company] shipyard (Rauma, Finland) for the USSR Academy of Sciences.

This system combines into a common entity the facilities for automating oceanologic experiments, automatic facilities for vessel navigation, including earth satellite communication facilities, facilities for acquisition of meteosynoptic data and facilities of electronic computer equipment in the form of a single-node network of various computers and crates with CAMAC modules, supported by the necessary interface facilities and software. The system includes a computer center (VTs) and over 10 permanently operating laboratory and thematic subsystems (see fig. 1).

Key:
1. EVM 1 [computer 1]
2. EVM 2 [computer 2]
3. T -- terminals
4. NML -- tape storage units
5. NMD -- disk storage units
6. VTs -- computer center
7. PGP -- board plotter
8. RGP -- roll plotter
9. PU -- printer
10. DGT -- digitizer
11. PSDU -- dual control communication subsystem
12. TM -- television video monitors
13. laboratory
14. N -- navigation
15. MS -- meteosynoptic
16. GF -- geophysical
17. GDL -- hydrological
18. GDKh -- hydrochemical
19. GB -- geological-bilogical
20. GDF -- hydrophysical
21. BKh -- biochemical
22. GKh -- geochemical
23. MB -- microbiological

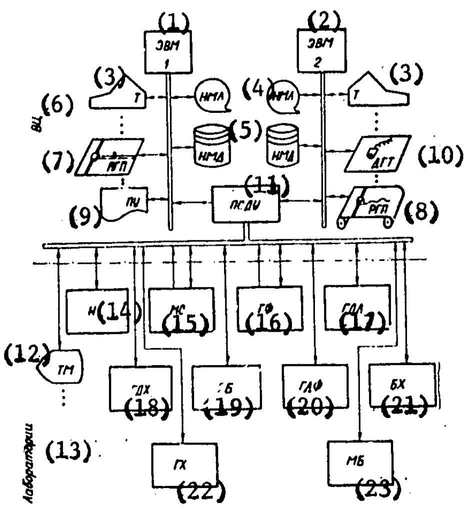

Fig. 1. System for automation of scientific research, including laboratory and thematic subsystems

The ship's computer center contains the computers for the data recording and processing subsystems. The laboratories are equipped with computers and thematic measuring complexes, as well as individual measuring instruments. The thematic laboratories are called upon to provide for acquisition, recording and processing (primary, and even secondary when necessary) of data pertaining to the fields of ocean and environmental sciences represented by them. Data are recorded in the form of values of sampled physical quantities (parameters) both during extended environmental characteristic measurements and as a result of one-time (discrete) measurements and laboratory analyses of environmental samples taken. Laboratory computers can operate in three modes: standalone, as preprocessors when data is recorded by a center computer and as terminals for center computers. Data recorded in laboratory subsystems in the form of sets of parameter values are accumulated in the center recording subsystem and ordered and then become accessible to users in other laboratories.

Maximal flexibility in building these systems is afforded by application of the hierarchical principle in designing the structure with a hierarchy distributed by levels for data recording, processing and storage and of the bus-modular method for organizing hardware and software at all levels.

By the bus-modular principle, we mean organizing a system of independent unit-modules united by common protocols for data and command exchange. Hardware modules capable of data exchange are linked by a bus, and the individual lines can be used for data transfer and address specification, synchronization and control. Buses can be machine-dependent, oriented to a specific family of computers, or machine-independent, oriented to a certain group of problems, and not to a type of computer. The latter, for example, include the CAMAC crate bus [2]. Each functional module capable of data exchange over the bus is assigned its own address (or group of addresses). Depending on system complexity, the functional modules may be individual hardware units (instruments) or entire subsystems. Data (messages) are exchanged with each module under control of the appropriate driver program. Preparation of messages for transfer, their reception and, when necessary, initiation of retransmission are performed by individual program modules.

The integrated system for the "Akademik Mstislav Keldysh" scientific research ship has four levels in the hierarchy (see fig. 2). Each level has modules with the capability of being programmed and performing particular processing of data received from the lower levels, including from primary transducers.

The top (first) level in the hierarchy consists of the data recording and processing subsystems for the ship computer center that are linked by the dual control communication subsystem. These subsystems operate independently of each other and have the capability of mutually starting and stopping programs and exchange of ready files of programs and data. In hardware composition, these subsystems largely duplicate each other and both have minicomputers, disk storage units with over 100M-byte capacity each, magnetic tape and floppy disk storage units, alphanumeric and graphic terminals, digitizers and other data input/output devices. Along with recording in the Integrated System, this provides the capability for substantial secondary (thematic) processing of data recorded during a trip, and for preparing data on media in a form suitable for transfer to shore centers, including for exchange with international data centers, immediately after the trip without additional processing. The main interface at the top level is the minicomputer output bus.

Functional modules in the lower level of the hierarchy with respect to computer center subsystems are the laboratory and thematic subsystems, as well as some additional data input, output and storage units, for example, the video monitors placed in various rooms on the ship. These functional modules are joined, just as in the computer center minicomputers, by the bus of the dual control communication

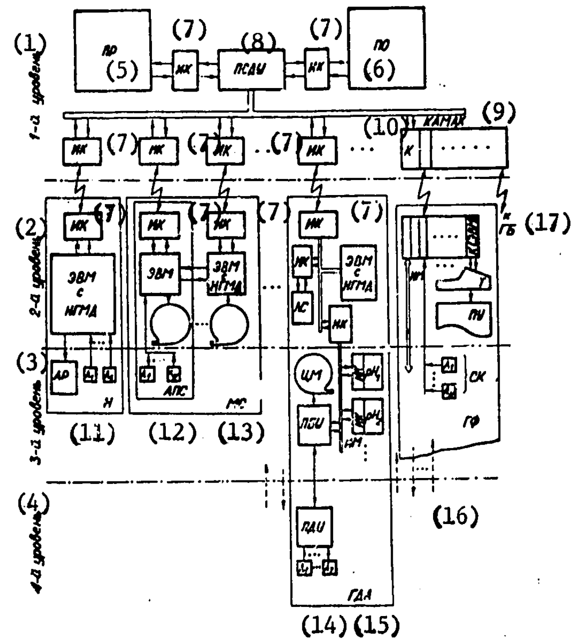

Fig. 2. Hierarchy in scientific research automation system

Key:

1. level 1
2. level 2
3. level 3
4. level 4
5. PR -- computer center data recording subsystem
6. PO -- computer center data processing subsystem
7. IK -- interface card
8. PSDU -- dual control communication subsystem
9. CAMAC [computer automated measurement and control]
10. K -- CAMAC crate controller
11. [reading top to bottom, left to right]
    EVM s NGMD -- computer with floppy disk storage
    AR -- automatic steering device
    D_1, D_6 -- transducers
    N -- navigational subsystem
12. EVM -- computer
    D_1, $D_?$ -- transducers
    APS -- automatic weather station
13. EVM s NGMD -- computer with floppy disk storage
    MS -- meteosynoptic subsystem
14. IK -- interface card
    LS -- laboratory salt gage
    TsM -- digital magnetic tape recorder
    PBU -- deck unit
    PDU -- underwater unit
    D_1, D_7 -- transducers
15. EVM s NGMD -- computer with floppy disk storage
    IK -- interface card
    $pH_{1,2}$ -- pH-millivoltmeters with interface cards
    IM -- IEC bus
    GDL -- hydrological subsystem
16. K (EVM) [to computer]
    IM -- IEC bus
    T -- terminal
    PU -- printer
    D_1, D_N -- transducers
    SK -- seismo-bar [kosa]
    GF -- geophysical subsystem
17. to geological-biological subsystem

subsystem, which as implied by its title, can be alternately under the control of both computers. With that, there is the capability of sharing the peripherals (disk storage, for instance) between the two computers, which together with mutual starting and stopping of programs and exchange of data files and programs, provides the capability of organizing a two-machine complex at the top level. When the recording subsystem computer goes down, its functions are assumed by the other computer. With that, data processing is temporarily halted, and the same version of the operating system and recording programs in use on the malfunctioning computer is loaded on the second computer. After recovery of operating capability, the first computer can again assume control of the functional modules in the laboratory and thematic subsystems, and the released resources of the second computer can be used for processing data recorded earlier.

The second level in the hierarchy is formed by the Navigational Subsystem, the Subsystem for the Sonic Depth Finders, the Automatic Weather Station, the Ship CAMAC Subsystem, as well as the seven laboratory subsystems having a computer in their composition. All subsystems except the CAMAC are considerably remote from the computer center. Therefore, data is transferred from them through serial communication lines (for example, in accordance with the RS-232 C standard [3]), to which are connected modems that effect full galvanic isolation of the subsystems. Communication between the computer center crates and the laboratories within the CAMAC subsysttm is effected through serial communication lines with high throughput (up to 1M bits/second) and special CAMAC modules playing the role of interface cards.

A feature of the second level subsystems is horizontal (between functional modules on the same level) as well as vertical (from level to level) communication, such as between, for instance, the automatic weather station and the meteosynoptic laboratory computer. The availability of horizontal communication in the system allows reducing the overall amount of equipment and raising the flexibility of the system as a whole through a different degree of processing of the indications from the same transducers and the use of thematic subsystems for laboratory resources. The main interfaces on the second level of the hierarchy are the machine-dependent buses of the laboratory and automatic weather station computers and the machine-independent bus for the CAMAC crate.

Subsystems in the third level of the hierarchy and autonomous laboratory instruments can be functional modules of second-level subsystems. Since all modules are connected through separate interface cards, expanding the system by connecting autonomous scientific instruments on the second level entails reducing the capabilities for reconfigurations and complicates programming. It is advisable to connect autonomous instruments to the third or lower levels of the hierarchy by standard interfaces, IEC buses for example [4].

There are two types of subsystems on the third level of the hierarchy in the integrated system: specialized units based on microprocessors and subsystems formed by instruments. Requirements imposed on third-level interfaces are largely conflicting in terms of throughput, minimization of interface apparatus, simplification and standardization of programs servicing input/output, capability of rapid subsystem reconfiguration, etc. Therefore, it is difficult to point to one universal method in building third-level subsystems and compromises have to be made. In the specialized units based on microprocessors, such as for example the scintillation counter in liquids in the microbiological laboratory, the buses of the appropriate families of microprocessors are used for data exchange between third-level modules. This apparatus is used for measurements and primary processing of data from analysis of environmental samples (sea water, most often). Data is processed in it quite thoroughly and fully, and generalized characteristics of samples are sent to the laboratory computers. The computer capacities of subsystems at higher levels are used largely only for statistical processing of results and for generalized analysis of sample characteristics. Data flows between these subsystems and those on the second level are not characterized by high intensity; therefore, communication between them can be implemented through a serial line (according to the RS-232 C standard, for example) and the appropriate interface card for each subsystem.

On the whole it can be stated that beginning at this level, machine-independent buses should be used. More characteristic for the third level in the hierarchy is two-way data transfer over a bus with an 8-bit width.

A typical representative of this trend is the above-mentioned IEC [International Electrotechnical Commission] bus, which, just as the CAMAC crate bus, is a universal means of interface in automating scientific research. Modules for communication with this bus are part of the equipment in all the laboratories on the scientific research vessel. The IEC bus permits combining into a subsystem the instruments distributed throughout the laboratories, including several controller instruments. They do not impose rigid restrictions on the designs, in contrast to the CAMAC crates, and permit building subsystems from instruments, series produced in various countries, that are intended both for operation within a system and for autonomous use. In the process, the capability is provided for remote addressing and changing an instrument address, building the simplest systems without a controller, and exchanging data, bypassing the controller, directly between the address source and one or more address listeners. The bus also implements a number of other capabilities [4, 5] and is the optimal for uniting autonomous instruments having various degrees of "intelligence." Let us note that theoretically, an IEC bus throughput up to 1M bytes/second is attainable at a length up to 20 m. Several interface cards for the IEC bus can be connected to one laboratory computer, and the group of instruments joined by each bus can be very complex subsystems at the third level of the hierarchy.

The fourth and lower levels of the hierarchy in the integrated system structure are formed by the deck and underwater devices of the various sounds and samplers, as well as the instruments and systems of various degrees of complexity that are connectable to the crate modules of the CAMAC subsystem. The availability in the CAMAC apparatus of modules for communication between CAMAC and the IEC bus is a very powerful means for automating laboratory research. This characteristic feature of the structure of the scientific research automation system being described affords it increased flexibility and the capability of adding to it.

Data obtained in laboratories can be stored for some time in the laboratory computers before transferring it to a subsystem. Data obtained at different times in different laboratories and in different regions of the study can be grouped into the same recording subsystem file. After preparation of the completed data files, they are output to magnetic tape and can be stored for a long time in an archive.

Used in this automation system is the flexible structure of self-identification of data [6] on the two upper levels of the hierarchy, under which all data obtained are supplied with labels (tags) indicating their type, properties, time and place of recording, etc. The system software structure presupposes that the entire set of parameters being recorded is divided into subsets, each of which is assigned to a specific laboratory. The structure for division of the set of parameters and their description is specified in the parameter description table. It is a resource for the computer center recording subsystem which can be modified and supplemented by the software method both before and during a trip by the vessel. The parameter description table determines the general research direction. Only values for those parameters described in this table can be measured and recorded. There are also a number of parameters, sufficiently important for all laboratories, the values of which can be added in the form of tags to the data obtained from laboratory subsystems to increase their information content. These include primarily information on the time and place of data recording, coordinates of the ship's location, on the state of the environment, etc. These parameters are updated periodically by the thematic subsystems and form the so-called status table. The procedure for updating status table parameter values differs from that for recording the experimental data being collected by the scientific equipment on the vessel. It is loosely related to current operations in laboratories during trips and essentially does not change from trip to trip. Therefore, in defining the integrated system structure, it was deemed expedient to separate the flows of status table parameter values from the main data flows and to organize additional communication channels to transfer them to the upper level. Organized this way are the channels from the navigation system (data on ship location), the automatic weather station (data on the environment) and from the subsystem for the sounding devices in the geophysical laboratory (data on depth).

A given set of ready files of recorded data is retrieved by using the directory, each record of which is created automatically upon completion of recording of a data file in turn. Elementary directory records describe the name and version of the completed file, the magnetic tape volume number, time and place of data recording, as well as the list of names (codes) recorded in the file of parameters.

Let us discuss the procedure for recording data from extended measurements during deep sounding of sea water by the hydrological laboratory apparatus (see figs. 3 and 4), fitted with transducers for pressure, temperature, electrical conduction, transmittance, concentration of hydrogen ions (pH), as well as a diaphragm pickup of the oxygen content in the water. This apparatus is lowered by using a special winch along with water samplers (bathometers) to 6500 m depth in the ocean and performs vertical sounding. Samples can be taken by the bathometers at any depth upon command from the deck unit sent manually or by computer. In one sounding, up to 12 sea water samples can be taken at various depths. On the ship, these samples undergo laboratory analyses which result in a large quantity of values of discrete parameters assigned to the various laboratories. In addition to transducers and bathometers, the lowered apparatus contains an electronic unit, protected from pressure, that effects time multiplexing (MP), analog-to-digital conversion (A/D) and frequency modulation (FSK) for transmission of the values obtained over the cable to the deck unit. The deck unit performs demodulation (DM), selection of the fields belonging to each transducer in the word received (SC), calculation on the data received of the corresponding engineering quantities (CALC), display of data

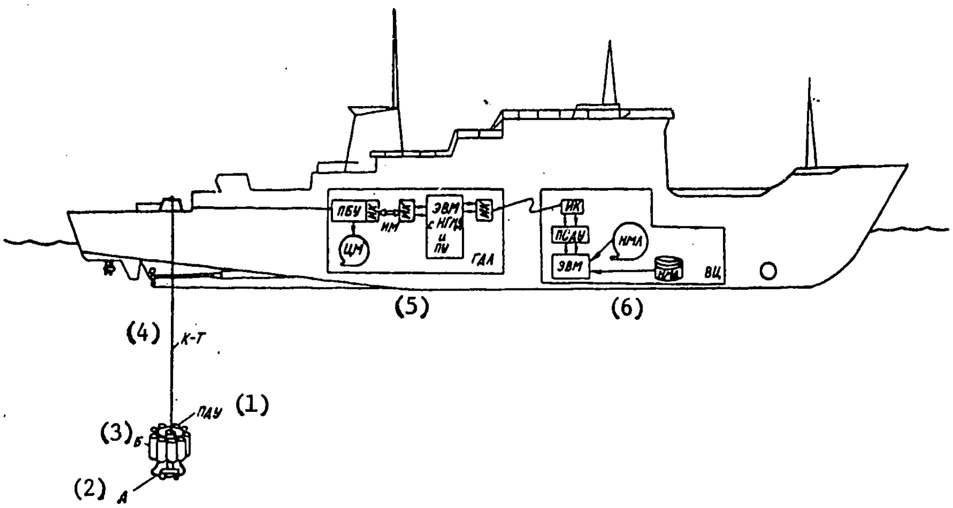

Fig. 3. Seawater sounding by hydrological laboratory apparatus

Key:

1. PDU -- underwater unit
2. D -- transducers
3. B -- bathometers
4. K-T -- cable
5. GDL -- hydrological subsystem
   PBU -- deck unit
   TsM -- digital magnetic tape recorder
   IK -- interface cards
   IM -- IEC bus
   EVM s NGMD i PU -- computer with floppy disk storage and printer
6. VTs -- computer center
   IK -- interface card
   PSDU -- dual control communication subsystem
   EVM -- computer
   NML -- magnetic tape storage unit
   NMD -- magentic disk storage unit

on a unit for preliminary checking (DISPL), formatting and check logging of "raw" data obtained from underwater unit on digital magnetic tape recorder (FORM and S), and also sends over the IEC bus to the laboratory computer messages in the same format as that of the data recorded on the digital magnetic tape recorder. The laboratory computer program effects selection of the cycle of the data and the time of their entry (SEL), and the bus interface card provides for addressing of the deck unit (ADDR), issuing to it the necessary commands (COMM) and synchronization when data is received (HS). In the laboratory computer, the data undergo functional conversions (F) with intermediate storage of results in memory (M). They are used to calculate (CALC) design parameters (salinity, seawater density, dynamic depth, etc.). For transfer to the computer center recording subsystem, the data are first formed into messages (FORM) standard for this scientific research automation system.

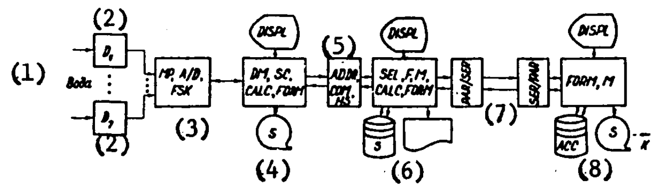

Fig. 4. Logging of data from extended measurements during depth sounding by hydrological laboratory apparatus

Key:

1. water
2. D_1, D_7 -- transducers
3. MP -- time multiplexing
   A/D -- analog-to-digital conversion
   FSK -- frequency modulation
4. DISPL -- display
   DM -- demodulation
   SC -- selection
   CALC -- calculation
   FORM -- formatting
   S -- storage
5. ADDR -- addressing
   COM -- commands
   HS -- synchronization
6. DISPL -- display
   SEL -- selection
   F -- functional conversion
   M -- memory
   CALC -- calculation
   FORM -- forming
   S -- storage
7. PAR/SER -- parallel-to-serial conversion
   SER/PAR -- serial-to-parallel conversion
8. DISPL -- display
   FORM -- forming
   M -- memory
   ACC -- accumulation
   S -- storage
   K -- keeping

Data is converted from parallel form to serial and back by the interface cards for the serial line of communication to the computer center computer and for the laboratory computer.

If the laboratory computer is malfunctioning, the experiment can still be continued according to the scheme described up to an including data logging on the digital magnetic tape recorder. Forming of the final files in this case is done later when the data is processed from the digital magnetic tape recorder on the computer for the ship computer center processing subsystem or on the laboratory computer after recovery of operating capability.

The logging subsystem computer programs add the necessary tags for location and environment, form (FORM) the data obtained in accordance with the protocols selected in the system, accumulate them on magnetic disks (ACC) and recopy the final files on magnetic tape (S) for keeping (K).

In transferring data from the place of origination to the place of logging, there occur delays, the resulting value of which depends on many factors, primarily on the specific mode of operation of the laboratory subsystem. Hardware delays are usually slight and can be taken into account analytically. The other portion of delays occur through distribution of processing and logging by levels of the hierarchy and by using the current schedule of programs for the logging subsystem; their values in practice cannot be determined analytically in each specific case. In the example described, the delay in transferring measurement data to the laboratory computer is measured in tenths of a second. In the laboratory computer, conversions and computations take 0.5-2 seconds as a function of the length of the corresponding branch of the program. Message transfer time over the serial line of communication (T_{trans}) with a 1200-baud throughput varies from 1 to 4 seconds as a function of message length. In general form, for the delay in transfer from the second to the third level taking repeat requests into account, one can write: $T = T_{pro} + T_{wait} + T_{prep} + nT_{trans} + (n-1)T_{resp}$, where T_{pro} is the execution time of the program accepting messages from the appropriate subsystem up to the time the data is received and transferred to the logging program; T_{wait} is the time waiting for use of the bus for the upper level (depends on how intensively the programs assigned for execution are using the procedures for exchange with modules having a higher bus priority than the given subsystem); n = 1, 2, 3 is the number of transfers over the communication line with regard to the three possible requests for repetition during transfer of the given message; T_{prep} is the message preparation time in the laboratory computer and T_{resp} is the response time of this computer to the byte for a repeat request. Thus, for the given example, the total delay in some cases may be 12-15 seconds. To prevent the effect of these delays on the quality of logging and capability of comparing logged data, it is advisable to assign the log time tags at the lower levels of the hierarchy (as close as possible to the place of origination of the data). Including real-time clocks in the individual laboratory instruments cannot be justified economically and is not always possible; therefore, in the scientific research automation system in question, hardware or software real-time clocks have been incorporated as part of all subsystems in the second level of the hierarchy and there are facilities for synchronizing them with the clocks in the logging subsystem. Let us note that including synchronizable real-time clocks in the second-level subsystems permits assigning the time tags also when the laboratory subsystems are operated in the offline mode, thereby raising the flexibility of the integrated system as a whole and creating the capability of restoring the final files in the logging subsystem at any time after performance of the experiment.

Conclusions

1. In developing scientific research automation systems for multipurpose scientific research vessels, maximum flexibility is afforded by using the hierarchical system structure with distributed processing of data received by levels of the hierarchy and use of the bus-modular method for organizing the hardware at all levels in the hierarchy.

2. In developing the software structure for scientific research automation systems, it is advisable to provide for a parameter description table as a modifiable resource of the logging subsystem. This table must contain descriptions of each parameter, describing thereby the entire set of parameters to be logged and assigning them to specific laboratory and thematic subsystems.

3. In developing the structure for scientific research automation systems, it is advisable to isolate common parameters and organize a table of their values that are updated periodically. It is advisable to separate the flows of values of parameters in this table from other data flows and send them to the top level in the hierarchy over separate lines of communication.

4. It is advisable to organize not only vertical, but also horizontal links between subsystems to increase the flexibility and extend the functional capabilities in the structure for scientific research automation systems.

5. The proper selection of interfaces for the various levels in the hierarchy is of special importance in building scientific research automation systems. It is advisable to use machine-dependent interfaces at the upper levels and machine-independent ones at the lower. Among the latter, there should be used primarily international standards such as CAMAC and the IEC bus, and the latter will apparently be used more extensively in these systems. Uniting the capabilities of both standards by using the appropriate CAMAC modules is the optimum for obtaining the maximally flexible system.

6. To organize a flexible structure for storing data and simplify processing of it, it is advisable to employ a system of data identification using tags. The paramount tags for ship scientific research automation systems are those for time, location and environment.

7. It is advisable to add the time tags as close as possible to the place of data origination. Optimum is the incorporation of real-time clocks in all subsystems in the second level of the hierarchy. Facilities to synchronize them are also required.

8. Is is advisable to provide a directory to facilitate retrieval of a specified set of finished files of logged data. Each elementary entry in the directory is created automatically upon completion of logging of each file in turn.

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AUTOMATED ENTERPRISE CONTROL SYSTEMS

Moscow AVTOMATIZIROVANNYYE SISTEMY UPRAVLENIYA PREDPRIYATIYAMI in Russian 1981 (signed to press 24 Mar 81) pp 2, 247-248

[Annotation and table of contents from book "Automated Enterprise Control Systems", by Vladimir Alekseyevich Andreyev and Gennadiy Petrovich Penkin, Izdatel'stvo "Finansy i statistika", 20,000 copies, 248 pages]

[Text] Annotation

This textbook gives the fundamentals of development and introduction of ASUP's [Automated Enterprise Control Systems]. It presents the principles of construction of ASUP's and the main concepts and definitions of data, mathematical, and program software and hardware. The authors consider the organization and sequence of development and introduction of ASUP's and the issues of their economic efficiency.

The book is intended for students at secondary specialized schools who are studying in the specializations "Planning at Machine Building Enterprises" and "Planning at Metallurgical Enterprises."

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PRINCIPAL ECONOMIC EFFICIENCY INDICATORS OF INTRODUCING AN ASUP

Moscow AVTOMATIZIROVANNYYE SISTEMY UPRAVLENIYA PREDPRIYATIYAMI in Russian 1981 (signed to press 24 Mar 81) pp 221-232

[Subchapters 8.2 and 8.3 from book "Automated Enterprise Control Systems", by Vladimir Alekseyevich Andreyev and Gennadiy Petrovich Penkin, Izdatel'stvo "Finansy i statistika", 20,000 copies, 248 pages]

[Text] Determining the economic efficiency of an ASUP [Automated Enterprise Control System] involves a number of special features which make it more difficult to calculate than the economic efficiency of using new equipment. Among these features are the following:

1. the impossibility of determining the quantitative parameters of the consequences of using the ASUP in a number of areas of an enterprise's production and management activity;

2. the extensive interchangeability of facilities and the great variation in the composition of ASUP hardware;

3. the significant effect that the organization of the control object has on the efficiency of results of the ASUP;

4. the effect of the dimensionality of problems being solved on the economic results of ASUP activity;

5. the great impact of selection of initial problems on the prospects of system development;

6. the comprehensive and interrelated character of all areas of ASUP functioning.

In other words, the ASUP is expected to assume the main burden in processing management information. Therefore, any shortcomings in this element will be reflected immediately in the efficiency of its functioning.

Calculating the annual volume of marketable output. The introduction of an ASUP makes it possible to increase the volume of marketable output with existing production capacities by raising the labor productivity of the primary workers and by better use of equipment. The increase in production volume is taken into account in calculations of economic activity if it is planned in future and current enterprise development plans. If the growth in volume of output is not planned, calculations of the economic efficiency of the ASUP take account only of the decrease in number of employees resulting from the rise in labor productivity.

The rise in the labor productivity of primary production workers results from decreases in work time lost within shifts, unproductive labor expenditures owing to organizational factors, and equipment downtime and underloading. These improvements are achieved as the result of the following:

1. optimization of technical-economic and operational-calendar planning and of decisions on equipment loading, sizes of batches, and cycles of launching and producing parts;

2. improvement of operational regulation of production based on receiving prompt, reliable information on the production situation;

3. evening out the production and marketing of output;

4. improving material-technical supply;

5. reducing the labor-intensiveness of output produced;

6. reducing losses from defective goods and unproductive expenditures.

The annual volume of marketable output (A_2) after introduction of the ASUP is calculated by the formula

$$A_2 = A_1 \cdot \nu, \qquad (8.1)$$

where ν is the coefficient of growth of production of output, and A_1 is the annual volume of sale of output before introduction from the ASUP, in thousands of rubles. The coefficient of growth of production of output is:

$$\nu = \frac{100 - a_2}{100 - a_1}, \qquad (8.2)$$

where a_1 and a_2 are losses of working time that affect the volume of output produced (unproductive work as a percentage of actual available working time) before and after the introduction of the ASUP, in percentage.

Calculating change in the prime cost of enterprise output. The amount of change in prime cost is determined by actual change in cost elements which are affected by introduction of the ASUP.

Current expenditures are grouped by sub-heading: raw and processed materials, fuel and energy for production needs, basic wages of production workers, deductions for social insurance, expenditures for preparation and incorporation of production, expenditures for equipment maintenance and operation, shop expenditures, general plant expenditures, losses from defective goods, other production expenditures, and nonproduction expenditures.

To calculate economic efficiency from these sub-headings individual expenditures are singled out and divided into conditional-permanent expenditures and variable expenditures.

Following this, the prime cost of output is:

$$C = C_{\text{пр}} + C_{\text{ур}}, \qquad (8.3)$$

where $C_{\text{пр}}$ is variable expenditures and $C_{\text{ур}}$ is conditional-permanent expenditures (in thousands of rubles.

The absolute savings from lowering prime cost by introduction of an ASUP into production is formed from the reduction of expenditures that are directly proportional to production volume.

The annual savings of variable expenditures is determined from the formula:

$$Э^A_{\text{пр}} = \Delta C^A_{\text{м}} + \Delta З^A + \Delta C^A_{\text{бр}} + \Delta C^A_{\text{непр}}, \qquad (8.4)$$

where $\Delta C_{\text{м}}^A$ is the savings from lowering cost for materials, $\Delta З^A$ is the savings on the wages fund, $\Delta C^A{}_{\text{бр}}$ is the savings from reducing losses owing to defective goods and $\Delta C^A{}_{\text{непр}}$ is the savings from reducing nonproductive expenditures (all figures in thousands of rubles).

The savings from reducing material expenditures is determined by the formula

$$\Delta C^A_{\text{м}} = C_{\text{пер}} \cdot \beta, \qquad (8.5)$$

where $C_{\text{пер}}$ is the overexpenditure of raw and processed materials before introduction of the ASUP (in thousands of rubles), and β is a coefficient that characterizes the possible decrease in overexpenditure of raw and processed materials after introduction of the ASUP.

The savings on the wages fund is determined by the formula

$$\Delta З^A = \Delta З_1{}^A - \Delta З_2{}^A, \qquad (8.6)$$

where $\Delta З_1{}^A$ is the savings from releasing engineering-technical personnel in the administrative apparatus, and $\Delta З_2{}^A$ is the slowdown in growth of the wages fund for primary workers taking into account the faster rate of growth of labor productivity and the growth rate of average wages (both figures in thousands of rubles).

The partial release of engineering-technical employees belonging to the administrative apparatus of the plant and the shops will be expressed as follows:

$$\Delta З_1{}^A = \Delta З_3{}^A + \Delta З_4{}^A, \qquad (8.7)$$

where $\Delta З_3{}^A$ is the savings on the wages fund with deductions for social insurance, achieved by reducing the number of engineers, technicians, and plant administrator personnel, and $\Delta З_4{}^A$ is the savings on the wages fund with deductions for social insurance, achieved by reducing the number of engineers, technicians, and shop administrative personnel (both figures in thousands of rubles).

The slowdown in growth* in the wages fund of primary workers is determined by the formula

$$\Delta 3_2^A = 3(\nu - 1)\alpha - \Delta 3^A , \tag{8.8}$$

where α is the coefficient of the ratio of the rate of growth in average wages to rate of growth in labor productivity of production workers — it is set by sectors taking into account the implementation of steps to raise production efficiency; 3 is the annual fund of primary and supplementary wages for production personnel with deductions for social insurance, in thousands of rubles; and, $\Delta 3^A$ is the reduction in supplementary pay for overtime work, in thousands of rubles.

The savings from reducing losses owing to defective goods ($\Delta C^A_{\text{бр}}$) is determined by direct calculation.

Introduction of an ASUP makes it possible to cut nonproduction expenditures which are included in shop and plant-wide expenditures:

$$\Delta C^A_{\text{непр}} = \Delta C^A_{\text{непр.з}} + \Delta C^A_{\text{непр.ц}} , \tag{8.9}$$

where $\Delta C^A_{\text{непр.з}}$ is the decrease in nonproduction expenditures in plant-wide expenditures, and $\Delta C^A_{\text{непр.ц}}$ is the reduction in nonproduction expenditures in shop expenditures (both figures in thousands of rubles). The decrease in nonproduction expenditures is determined by direct calculation.

Using these calculations it is possible to determine the amount of the annual savings of variable expenditures (8.4). Conditional-permanent expenditures are included in prime cost without change.

The slowdown in growth of plant expenditures at the enterprise with an operating ASUP is determined by the formula:

$$\Delta C_{\text{ц}}^A = C_{\text{ц}}(\nu - 1)P_{\text{ц}} - \Delta 3_{\text{ц}}^A - \Delta C_{\text{непр.ц}} , \tag{8.10}$$

where $C_{\text{ц}}$ is shop expenditures before introduction of the ASUP, in thousands of rubles, and $P_{\text{ц}}$ is the coefficient of dependence of growth in shop expenditures on growth in production volume.

The slowdown in growth of plant-wide expenditures after introduction of the ASUP is determined as follows:

$$\Delta C_3^A = C_3(\nu - 1)P_3 - \Delta 3_3^A - \Delta C^A_{\text{непр.з}} , \tag{8.11}$$

where C_3 is plant-wide expenditures before introduction of the ASUP, in thousands of rubles, and P_3 is the coefficient of dependence of growth in plant-wide expenditures on growth in production volume.

The prime cost of output after introduction of the ASUP is expressed as follows:

$$C^A = C - 3^A_{\text{пр}} + DC_{\text{ц}}^A + DC_3^A + C^A_{\text{экс}} , \tag{8.12}$$

where $C^A_{\text{экс}}$ is operating expenditures for functioning of the ASUP (maintenance of the computer center and system operation), and C is the prime cost of output before introduction of the ASUP.

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* Slowdown in growth reflects the fact that the use of an ASUP reduces costs accordingly, but these expenditures must be subtracted from the total amount when determining the total savings.

To determine the total savings from change in prime cost as a result of introduction of the ASUP it is necessary to obtain expenditures per ruble of marketable output before and after introduction:

$$C_1 = \frac{C}{A_1}; \quad C_2 = \frac{C^A}{A_2}, \qquad (8.13)$$

where C_1 and C_2 are expenditures in kopecks per ruble of output sold before and after introduction of the ASUP, and A_1 and A_2 are the volumes of marketable output before and after introduction of the ASUP respectively, in thousands of rubles.

Calculating capital expenditures for design and setting up the ASUP. Expenditures related to the design and introduction of the ASUP are expressed by the formula:

$$K_Д{}^A = K_П{}^A + K_O{}^A + \Delta O_C{}^A + K_Л{}^A - K^A_{выс}, \qquad (8.14)$$

where $K_П{}^A$ is expenditures for system design, $K_O{}^A$ is expenditures for purchase of the set of ASUP hardware, $\Delta O_C{}^A$ is change in the amount of working capital with introduction of the ASUP, $K_Л{}^A$ is the balance value of liquidatable equipment, devices, buildings, and structures which were not in use before introduction of the ASUP and cannot be sold (subtracting scrap metal), and $K^A_{выс}$ is the balance value of released equipment, devices, buildings, and structures which will be used in the ASUP or other sectors of production, or sold on the side (all figures in thousands of rubles).

The calculation of change in norm-controlled working capital with introduction of the ASUP should take account of the increase in working capital related to growth in the volume of output sold resulting from introduction of the system, as well as the reduction in working capital (resulting from stepping up the rate of turnover of working capital):

$$\Delta O_C{}^A = O_C - O_C{}^A, \qquad (8.15)$$

where O_C and $O_C{}^A$ are the specific amounts of capital investment before and after introduction of the ASUP respectively, in thousands of rubles.

The balance value of expendable (liquidatable) equipment, devices, buildings, and structures calculated by the formula

$$K^A_{выс\,(л)} = K^A(1 - H_a T_{экс}), \qquad (8.16)$$

where K^A is the initial value of existing equipment, devices, buildings, and structures, in thousands of rubles, H_a is the annual depreciation norm for full replacement, in fractions, and $T_{экс}$ is the time that existing production equipment, devices, buildings, and structures has been in use, in years.

Determination of the annual economic impact from introduction of the ASUP. When determining the economic efficiency of an ASUP it is mandatory to correlate all indicators by time and prices used to determine indicators and by elements of expenditures. All value indicators are determined by wholesale prices and wage and salary rates existing at the moment of the calculation.

The basis for comparison that is used in determining the expected annual economic impact is planned indicators of production-management activity at an existing enterprise, and the technical-economic indicators of the plan for those areas of activity which are directly affected by the ASUP at a new construction site where setting up an ASUP was not envisioned.

Annual growth in profit (annual savings) is calculated by the formula

$$Э_{год} = \left(\frac{A_2 - A_1}{A_1}\right) П_1 + \left(\frac{C_1 - C_2}{100}\right) A_2. \qquad (8.17)$$

where $П_1$ is profit from sale of output before introduction of the ASUP, in thousands of rubles, and A_1, A_2, C_1, and C_2 are obtained from formula (8.1)-(8.13) above.

With an operating ASUP, nonproduction expenditures related to payment of fines and penalties are reduced as the result of improving monitoring of performance of economic contracts, payments of accounts with suppliers, and receiving payments from customers, in other words, through operational control of enterprise financial relations. The additional profit received from eliminating these expenditures, which are not part of the prime cost of output produced, is considered additionally in annual growth in profit $Э_{год}$ and, correspondingly, in the annual economic impact Э.

The annual economic impact is determined by the formula

$$Э = \left[\left(\frac{A_2 - A_1}{A_1}\right) П_1 + \left(\frac{C_1 - C_2}{100}\right) A_2\right] - E_н K_д^А, \quad (8.18)$$

where $E_н$ is the normative coefficient of the economic efficiency of capital investment in the particular sector, and $K_д^А$ is capital expenditures for designing and setting up the ASUP, in thousands of rubles.

The $E_н$ operating in the sector is adopted when determining annual economic impact; in the absence of such a coefficient, $E_н$ is taken as equal to 0.15.

The annual economic impact shows the degree of economic efficiency of the ASUP and is also used in payment of bonuses for introduction of the system.

The efficiency of expenditures is determined by the following formulas

$$T = \frac{K_д^А}{Э_{год}}; \quad E_р = \frac{Э_{год}}{K_д^А} > E_{н.в.т}, \qquad (8.19)$$

where T is the payback time of expenditures for the ASUP, which means the period of time in which expenditures are repaid by savings of production costs and additional profit from sale of output, $E_р$ is the calculation coefficient of efficiency of expenditures and $E_{н.в.т.}$ is the normative coefficient of economic efficiency from introduction of computer equipment.

8.3. Example of Determining the Economic Efficiency of an ASUP

The calculation is based on the hypothetical data (shown in Table 8.1 below) for analysis of the economic activity of an enterprise in the period preceding introduction of an ASUP. The analysis was made in 1976, then development of the system began in 1977 and introduction of the ASUP was completed in 1981.

Table 8.1. Indicators of the Economic Activity of an Enterprise That Is Introducing an ASUP.

			Level of Indicator		
No	Name of Indicator	Symbol	Unit of Measure	Before ASUP	After ASUP
1	2	3	4	5	6
1	Annual volume of output sold	A	1,000's of rubles	95,000	See calculation
2	Losses of working time within shift	A	%	8.8	7.0
3	Prime cost of annual production of marketable output	C	1,000's of rubles	82,071	See calculation
4	Raw and processed materials	C_M	1,000's of rubles	39,816	40,214
	Included in above, variable part	$C_{пер}$	1,000's of rubles	640	See calculation
5	Wages (primary, supplementary) and deductions for social insurance for production workers	3	1,000's of rubles	9,000	See calculation
6	Shop expenditures	$C_ц$	1,000's of rubles	12,500	See calculation
7	General plant expenditures	C_3	1,000's of rubles	7,000	See calculation
8	Coefficient of possible decrease in overexpenditure of raw and processed materials	β			0.3
9	Coefficient of the ratio of the growth rate of average wages to the growth rate of labor productivity	α			
10	Decrease in supplementary pay for overtime work (10% of total amount of pay supplements without ASUP)	$3_п^A$	1,000's of rubles		3
11	Reduction in losses from defective goods after introduction of ASUP	$C_{бр}^A$			313
12	Decrease in engineering-technical and administrative personnel engaged in data processing:				
	Plant administration	$3_з^A$	1,000's of rubles / Persons		32.3 / 27

[Table continued, next page]

[Table 8.1 continued]

No	Name of Indicator	Symbol	Level of Indicator: Unit of Measure	Before ASUP	After ASUP
1	2	3	4	5	6
	Shops	$З_ц^A$	1,000's of rubles / Persons		72 / 60
13	Coefficient of growth of shop expenditures depending on growth in production volume	$P_ц$			0.4
14	Coefficient of growth in general plant expenditures depending on growth in production volume	P_3			0.3
15	Decrease in nonproduction expenditures:	$\Delta C^A_{непр}$	1,000's of rubles		220.0
	By shops	$\Delta C^A_{непр.ц}$	1,000's of rubles		120.0
	For plant	$C^A_{непр.з}$	1,000's of rubles		100.0
16	Expenditures for functioning of ASUP (in year)	$C^A_{экс}$	1,000's of rubles		300
17	Expenditures to design the system	K_π^A	1,000's of rubles		640
18	Expenditures to purchase ASUP hardware	K_o^A	1,000's of rubles		2,000
19	Volume of working capital	O_c	1,000's of rubles	28,500	See calculation
20	Coefficient of decrease in working capital after introduction of ASUP	$H_{об}$			0.05
21	Balance cost of liquid datable equipment minus value of scrap metal	K_π^A	1,000's of rubles		2.1
22	Balance cost of equipment released and sold on the side	$K^A_{выс}$	1,000's of rubles		8.2

The coefficient of growth of production of output:

$$\nu = \frac{100 - a_2}{100 - a_1} = \frac{100 - 7}{100 - 8,8} = 1,01.$$

The volume of marketable output after introduction of the ASUP

$$A_2 = A_1 \cdot \nu = 95,000 \cdot 1.01 = 95,950 \text{ (thousands of rubles).}$$

The savings of raw and processed materials achieved by reducing overexpenditures

$$\Delta C^A_M = C_{\text{пер}} \cdot \beta = 640 \cdot 0.3 = 192 \text{ (thousands of rubles).}$$

The savings from releasing engineering-technical personnel in the administrative apparatus

$$\Delta 3_1^A = \Delta 3_ц^A + \Delta 3_3^A = 72 + 32.4 = 104.4 \text{ (thousands of rubles).}$$

The slowdown in growth of the wages fund for primary workers by reducing expenditures for overtime work

$$\Delta 3_2^A = 3(\nu - 1)\ \alpha - \Delta 3_д^A = 9,000\ (1.01 - 1) \times 0.3 - 3 = 24 \text{ (thousands of rubles).}$$

The total savings for the wages fund

$$\Delta 3^A = 104.4 - 24 = 80.4 \text{ (thousands of rubles).}$$

The decrease in nonproduction expenditures

$$\Delta C^A_{\text{непр}} = \Delta C^A_{\text{непр.з}} + \Delta C^A_{\text{непр.ц}} = 100 + 120 = 220 \text{ (thousands of rubles).}$$

The total annual savings of variable expenditures

$$Э^A_{\text{пр}} = \Delta C^A_м + \Delta 3^A + \Delta C^A_{\text{бр}} + \Delta C^A_{\text{непр}} = 192 + 80,4 + 313 + 220 = 805,4 \text{ (thousands of rubles).}$$

The slowdown in growth of enterprise shop expenditures

$$\Delta C_ц^A = C_ц(\nu - 1)\, P_ц - \Delta 3_ц^A - \Delta C^A_{\text{непр.ц}} = 12500\,(1,01 - 1)\, 0,4 - 72 - 120 = -142 \text{ (thousands of rubles)}$$

The slowdown in growth of plant-wide expenditures

$$\Delta C_з^A = C_з(\nu - 1)\, P_з - \Delta 3_з^A - \Delta C^A_{\text{непр.з}} = 7000\,(1,01 - 1)\, 0,3 - 32,4 - 100 = -111,4 \text{ (thousands of rubles)}$$

The prime cost of output after introduction of the ASUP

$$C^A = C - Э^A_{\text{пр}} + \Delta C^A_ц + \Delta C_з^A + C^A_{\text{экс}} = 82892 - 805,4 - 142 - 111,4 + 300 = 82133,2 \text{ (thousands of rubles)}$$

Expenditures per ruble of marketable output before and after introduction of the ASUP

$$C_1 = \frac{C}{A_1} = \frac{82071}{95000} = 86{,}39 \quad \text{(kopecks)}$$

$$= 85{,}6 \quad \text{(kopecks)}$$

Annual savings

$$Э_{год} = \left(\frac{A_2 - A_1}{A_1}\right) П_1 + \left(\frac{C_1 - C_2}{100}\right) A_2 =$$

$$= \frac{95950 - 95000}{95000} (95000 - 82071) + (86{,}39 - 85{,}6)\, 95950 =$$

$$= 129{,}29 + 758 = 887{,}29 \quad \text{(thousands of rubles)}$$

Capital expenditures for setting up and introducing the ASUP

$$K_д{}^A = K_П^A + K_о{}^A + \Delta O_с{}^A + K_л{}^A - K_{выс}^A;$$

$$O_с{}^A = O_с{}^у (1 - H_{об})\, 28500 \cdot 1{,}01 \cdot 0{,}95 = 27345{,}75 \quad \text{(thousands of rubles)}$$

$$\Delta O_с{}^A = O_с{}^у - O_с{}^A = 28785 - 27345{,}75 = 1439{,}25 \quad \text{" "}$$

$$K_д{}^A = 640 + 2000 - 1439{,}25 + 2{,}1 - 8{,}2 = 1194{,}65$$

The annual economic impact

$$Э = \left(\frac{A_2 - A_1}{A_1}\right) П_1 + \left(\frac{C_1 - C_2}{100}\right) A_2 - E_н \cdot K_д{}^A = 887{,}29 -$$

$$- 0{,}15 \cdot 1194{,}65 = 708{,}1 \quad \text{(thousands of rubles)}$$

The calculated coefficient of efficiency of expenditures

$$E_р = \frac{Э_{год}}{K_д{}^A} = \frac{887{,}29}{1194{,}65} = 0{,}7.$$

Comparison of the magnitude of the calculated coefficient E_p with the normative value of this indicator enables us to establish that the ASUP being introduced is efficient ($E_p > E_н$). The payback time

$$T = \frac{K_д{}^A}{Э_{год}} = \frac{1194{,}65}{887{,}29} = 1{,}3 \quad \text{(years)}$$

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AUTOMATED CONTROL SYSTEM AT DNEPROPETROVSK METALLURGICAL PLANT IMENI PETROVSKIY

Moscow AVTOMATIZIROVANNYYE SISTEMY UPRAVLENIYA PREDPRIYATIYAMI in Russian 1981 (signed to press 24 Mar 81) pp 233-235

[Subchapter 9.1 from book "Automated Enterprise Control Systems", by Vladimir Alekseyevich Andreyev and Gennadiy Petrovich Penkin, Izdatel'stvo "Finansy i statistika", 20,000 copies, 248 pages]

[Text] At the present time ASUP's [Automated Enterprise Control Systems] are being set up at 51 ferrous metallurgical enterprises [24]. By subsectors they break down as follows: metallurgy — 47 percent; pipe production — 22 percent; mining — 17 percent; general metal products — eight percent; coke-chemical — four percent; refractory products — two percent. The sector has 192 computers, 65 of them third-generation. Accounting jobs make up the bulk of the tasks of the ASUP's. About 8,000 persons are engaged in setting up the ASUP's.

The Dnepropetrovsk Metallurgical Plant imeni Petrovskiy is one of the enterprises at which work is underway to set up an ASUP. By the end of the 10th Five-Year Plan the enterprise will have incorporated 112 tasks in seven subsystems. The most efficient groups of tasks are:

a. planning, operational accounting, and monitoring performance of orders;

b. planning, accounting, and analysis of wages;

c. planning, operational bookkeeping, analysis, and control of stocks of material assets.

The basic hardware of the second phase of the ASUP is a machine complex consisting of two computers, a Minsk-22 and an YeS-1020. A distinctive feature of the second phase is the use of display equipment and developing interactive "man-machine" systems.

Operational information on the course of production in the primary shops of the plant is received and stored on YeS-1020 magnetic media. On demand by five subscribers this information can be outputted to a screen and used for its designated purpose of improving control of primary production. It takes 0.5 seconds to output one videogram. Table 9.1 below shows a possible videogram.

Table 9.1. Prime Cost of a Unit of Output, rubles

Shop	According to Plan	Actual	Deviation for Production, rubles
Blast Furnace	61.00	61.80	+138,900
Open Hearth Furnace	70.64	71.24	+ 29,200
Convertor	79.75	81.89	+180,000
Rail Block	89.37	89.57	+ 19,600
550 Mill	109.28	109.79	+ 10,900
3000 Mill	108.77	109.25	+ 19.3
	For the Plant		+397,900

The Dispatcher interactive system is now being introduced. It will make it possible to establish direct communication between the plant dispatcher and the computers. After preliminary processing the computer will output information to punched tape, and with teletype it will be transmitted to higher levels. Introduction of the interactive system will eliminate manual labor by the computer operator to punch about 6,000 characters of daily information, the mistakes which an operator can make, and the intervention of uninformed persons in the process of preparing important and responsible information.

The problem set called "Analysis of Deviation of Coke Expenditure and Productivity of Blast Furnaces by Factors" is a part of the automated subsystem called "Operational Control of Primary Production." This set of tasks processes operational and monthly information received from the plant services. As input information it uses the results of the sets of tasks called "Accounting for Blast Production" and "Accounting for Raw Materials." The input information, prepared on punched tape (an ST-2M unit) and received from the Minsk-22 computer, is fed to the YeS-1020 computer, monitored, and processed in conformity with algorithms.

The results of problem-solving, represented in the form of eight documents for blast furnaces and for the shop, are used by the plant services: the blast furnace shop, the central plant laboratory, and the production division. The standard timing of this decision-making is three times a week. When the services demand it decisions can be made once every day.

The system software is based on the DOS YeS-1020 disk operating system.

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OPTICAL PROCESSING

UDC 535.375.55

RECORDING, RECONSTRUCTION (INVERSION) OF WAVEFRONT OF LIGHT, SELF-FOCUSING--NEW EFFECTS IN STIMULATED RAMAN SCATTERING OF LIGHT

Leningrad GOLOGRAFIYA I OPTICHESKAYA OBRABOTKA INFORMATSII: METODY I APPARATURA in Russian 1980 (signed to press 31 Dec 80) pp 39-55

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[Text] New effects in the stimulated Raman scattering of light (SRS) have been discovered and studied experimentally: 1) reconstruction of the divergence, brightness, amplitude and phase of exciting laser light, and 2) the formation of a multifocus structure in an SRS beam. The image of an object--a transparency--illuminated by an exciting laser beam is reconstructed in stimulated Raman scattering (SRS) so that longitudinal and transverse magnification obey the laws of holography. Reconstruction of the wavefront of light takes place in consequence of the amplification of SRS at intensity maxima of the exciting light and of diffraction in absorption holograms formed by laser radiation in an amplifying medium. Our experiments have demonstrated that under certain conditions the focal structure in an SRS beam does not destroy the effect of reconstruction of the wavefront.

It has been discovered experimentally that when a certain thickness of a layer of scattering matter is exceeded over a certain range of the power density of exciting radiation in stimulated Raman scattering (SRS), a number of physical effects arise which were previously unknown in the molecular scattering of light. It has been discovered that SRS propagated in the direction opposite the exciting radiation--"backwards"--in terms of brightness, divergence and a number of other parameters becomes close to the exciting laser radiation striking the scattering medium. When a three-dimensional object--a transparency--is introduced into the pumping beam, a three-dimensional image of it, obeying the laws of holography, is reconstructed in the SRS beam. It was possible to discover the holographic nature of the phenomenon precisely in SRS, because of the considerable shift in the frequency of the scattered light relative to the frequency of the exciting radiation. The amplitude and phase characteristics of the pumping beam are reconstructed in "forward" and backward" SRS beams. The wavefront of "forward" SRS is similar with some degree of accuracy to the pumping wavefront, and the wavefront of "backward" SRS is with some degree of accuracy "inverted" relative to the pumping wavefront. The SRS beam, being propagated in the medium, is broken up into a number of focal regions. The longitudinal and transverse dimensions of these focal regions are determined by the power density of stimulated Raman scattering of light. Self-focusing of the stimulated Raman scattering of light is in a number of cases the reason leading to destruction of the effect of reconstruction of the wavefront of light.

This article is devoted to the results of the experimental discovery and study of these new physical effects in stimulated Raman scattering.

1. Reconstruction of Amplitude and Phase of Intense Light Waves in Stimulated Raman Scattering

Stimulated Raman scattering of light was produced in liquid nitrogen ($\Delta\nu$ = 2300 cm^{-1}), a single crystal of calcite ($\Delta\nu$ = 1085 cm^{-1}), in carbon bisulfide ($\Delta\nu$ = 656 cm^{-1}), piperidine ($\Delta\nu$ = 2936 cm^{-1}), acetone ($\Delta\nu$ = 2921 cm^{-1}), nitrobenzene ($\Delta\nu$ = = 1345 cm^{-1}), benzene ($\Delta\nu$ = 992 cm^{-1}), toluene ($\Delta\nu$ = 1003 cm^{-1}) and cyclohexane ($\Delta\nu$ = 882 cm^{-1}) by means of giant pulses of a ruby and of the second harmonic of a neodymium laser with a length of $20 \cdot 10$ ns^{-9} and $20 \cdot 10$ ns^{-12} [as published].

The field of laser radiation striking the scattering medium represents the interference of the intense beam generated by the crystal and weak beams originating as the result of the diffraction of the intense beam in parts of the apparatus (diaphragms, inhomogeneities of the apparatus's optical elements and the like).

If the intensity of the diffracted light is very low, then it is possible to disregard the interference of these beams with the intense wave of laser radiation. That is, it is possible to assume that in the light striking the medium only the zeroth order of diffraction is present, i.e., light having traveled the path to the cell without deflection. Conditions close to this case were realized in [1]. SRS was produced in liquid nitrogen by means of the giant pulse of a ruby laser. The radiation was concentrated in the TEM mode. A practically plane laser wave with a Gaussian distribution of intensity struck the lens and was focused onto a cell with the scattering substance. A study was made of the dependence on the thickness of the scattering layer and on the pumping energy of the divergence, brightness and distribution of intensity in the long-range field of SRS propagated in the direction of the exciting radiation--"forward"--and in the opposite direction--"backwards."

According to the generally accepted notions, SRS originates as the result of the amplification of pulses of Raman scattering spontaneous noise. Actually, the experiment has demonstrated that in a thin layer of a medium, even with excitation by means of a single-mode laser, SRS is incoherent. The brightness of SRS is much less than the brightness, and its divergence is considerably greater than the divergence, of the original laser radiation (cf. fig 1a). However, when certain values of pumping and thickness of the layer of material are reached, the divergence, distribution of intensity in the long-range field and the brightness of "backwards" SRS and of the laser radiation become close (cf. fig 1b). A practically plane wave is reconstructed with "backward" SRS when the radiation of a single-mode laser passes through the medium. The medium, as it were, reflects the laser radiation "backwards" with a shift in frequency equal to the most intense intramolecular vibration of matter. In stimulated Brillouin scattering (SBS), when the frequency of the exciting radiation is close to the frequency of the scattered light, this phenomenon has been given the name "inversion" of the wavefront of light [2]. Let us note that producing an inverted beam of scattered light both in SBS and SRS does not at all require the introduction of a "phase" plate into the exciting light beam [2]. The general nature of phenomena with SRS [1] and SBS [2] was reported on in [3]. The reconstruction of a number of parameters of the laser radiation in "backward" SRS receives an explanation if attention is paid to the nature of the distribution of pumping power density along the cell with the scattering substance in the excitation of SRS by means of a focused light pulse with a length of 10^{-9} ns (fig 2). The power density of the exciting light, I_0, is greatest in the space of the medium bounded by the pumping beam near the focal point of the lens. In these ranges even with relatively low energy of the laser's giant pulse the power density of the exciting radiation reaches the SRS saturation level and the distribution of intensity over the cross section of the SRS beam does not depend on the distribution of intensity of the laser radiation. Being propagated primarily in the space bounded by the beam of exciting radiation, with a certain value of the gain increment, $g\ell I_0$, SRS becomes directional and coherent. The high directivity and coherence of SRS are associated with the preferred amplification of components of spontaneous noise with wave vectors parallel and antiparallel to the pumping wave vector. It is interesting to note that the directivity of the SRS beam becomes close to the directivity of the laser radiation with a gain increment value of $g\ell I_0 > 15$.

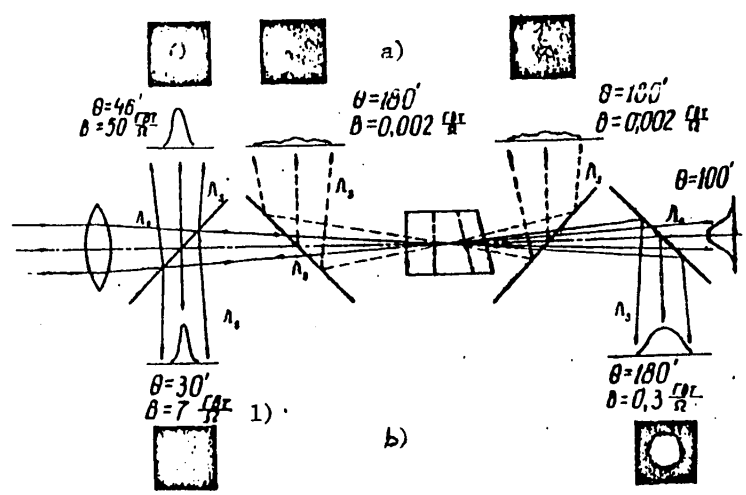

Figure 1. Divergence--θ, Brightness--B, Distribution of Intensity in Long-Range Field of Laser Radiation--λ_0, SRS--λ_s "Forward" and "Backward" in a Layer of Liquid Nitrogen with Thickness of a) 8 mm with Pumping Power of 10 MW/cm^2, and b) 100 mm with Pumping Power of 10 MW/cm^2

Key: 1. GW/Ω

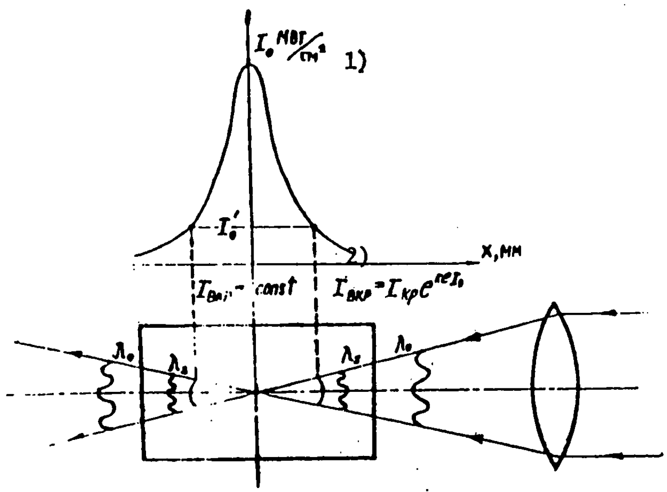

Figure 2. Distribution of Pumping Power Density--I_0, Along Cell in Excitation of SRS by Means of Focused Light Pulse; I_0'--Pumping Power with SRS Saturation

Key:
1. MW/cm^2
2. I_{VKR} [SRS]

Experimental studies and theoretical estimates in [4] have demonstrated that when this value of the gain increment is reached in the medium the origin of distributed feedback (ROS) is also possible in stimulated scattering, which, in turn, can be the reason for an increase in brightness and directivity of stimulated-scattered light. The analysis of the reasons for the origin of and of the influence of distributed feedback on the parameters of stimulated-scattered light in each specific case is a separate problem and can be performed primarily experimentally. Reproduction of the distribution of amplitude over the cross section [words missing] of the SRS beam by the pumping field. In this configuration of the experiment the pumping power density is minimal in the space of the medium adjacent to the cell's inlet and outlet windows. The experiment demonstrates that this layer accomplishes the transfer of information on the distribution of pumping amplitude to the SRS beam. Reproduction of the pumping amplitude in the SRS field does not take place with a pumping power density near the cell's windows which reaches the level of SRS saturation.

Experiments with the excitation of SRS in liquid nitrogen by means of a single-mode laser have demonstrated that with SRS a wave is reconstructed which is close to the incident wave not only in amplitude but also in phase characteristics. However, only subsequent experiments with reconstruction of the image in SRS made it possible to establish the accuracy of the reproduction of amplitude and phase with SRS and to understand sufficiently the physics of the phenomenon.

2. Reconstruction of Image in Stimulated Raman Scattering of Light

It was found in [5-9] that the introduction into a beam of laser radiation of a three-dimensional semitransparent object is accompanied by reconstruction of its three-dimensional image in "forward" and "backward" SRS beams. The experimental setup with the transparency is essentially not different from the previous setup. The introduction into the optical circuit of a transparency with specific dimensions of inhomogeneities makes it possible to control the relative intensity of light beams of various orders of diffraction, which is convenient for studying the properties of the distinctive optical system discussed and for studying the nature of reconstruction of the image with stimulated scattering.

A screen with wire 2 to 3 microns thick and cell dimensions of 600 microns was used as the object in the experiments. With the stimulated scattering of light the zeroth order of diffraction is reconstructed, corresponding to the laser's light which passes through the object without deflection, and higher orders originating as the result of diffraction of the direct laser beam at the object's edges. Let us cover part of the SRS beam with a nontransparent shield. In the plane of the image reconstructed in SRS, in the part covered by the shield, outlines of the image are visible which are constructed by beams of a higher order of diffraction propagated at an angle to the optical axis (cf. fig 3). The image reconstructed with SBS was at the same distance from the cell as the object and with SRS was shifted and altered in transverse scale.

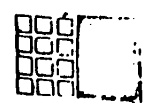

Figure 3. Distribution of Dense Areas on Photographic Plate in Plane of Image of Screen Object Reconstructed with "Backward" Stimulated Scattering. The Right Half Corresponds to the Covered Stimulated Scattering Beam.

The following experimental results prove the holographic nature of the reconstructed image in the stimulated scattering of light. An image was reconstructed in the stimulated-scattered beam regardless of what distance the object was from the cell; a real image of the object, produced by means of a lens (cf. fig 4), was found outside or inside the medium. The magnification and position of the image reconstructed in the SRS beam were such that the minima and maxima of the interference patterns of the pumping and "backward" SRS beam always coincided with the "inlet" window of the cell for the laser radiation and the "outlet" for SRS. Knowing from experimentation the position and scale of the real image of the object (d_s) reconstructed with SRS, from the lens formula it is possible to determine the position of the corresponding virtual image (m_s), representing, as it were, the source of waves reconstructed with SRS. It is possible to assume that the three-dimensional interference pattern of the pumping field is created by a pair of point sources, one of which is in line with the focal point of the lens (F), and the other with a random point (C') of the real image of the object. Then with "backward" SRS the interference pattern is created, as it were, by another pair of sources, one of which is in line with the corresponding point (C_{ms}) of the virtual image (m_s) and the position of the other it is not complicated to determine from the condition for matching of the interference patterns for SRS and pumping near the cell's outlet window. As the experiment demonstrated, the magnification of the image, d_s, is always such that the second source of interfering SRS waves coincides with the focal region of the lens. In this case the magnification, N, and the position, v_s, of the image, m_s, in the SRS beam is described by the simple relationships:

$$N = \left[1 + \frac{v_0}{u_0}\left(\frac{1}{\mu} - 1\right)\right]^{-1},$$
$$v_s = \left(\frac{\mu}{v_0} + \frac{1-\mu}{u_0}\right)^{-1}, \quad (1)$$

where $\mu = \lambda_s/\lambda_0$, and λ_0 and λ_s are the pumping and SRS wavelengths.

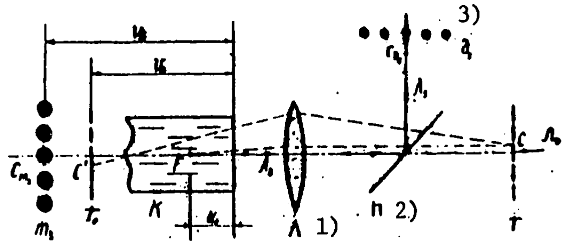

Figure 4. Diagram of Reconstruction of Image of Object in "Backward" SRS Beam: T--object--transparency; P--rotating plate; L--lens; K--cell; d_s--real image of object reconstructed in SRS

Key:
1. L
2. P
3. d_s

The relationships gotten for magnification of the image reconstructed in the SRS beam agree with the expression familiar in holography for reconstructing an image by means of a plane hologram with coinciding sources of reference and reconstructed waves. Shifting the cell along the optical axis of the system relative to the three-dimensional interference pattern for pumping results in a change in the position of intensity minima and maxima in the plane of the cell's outlet window. The magnification and the position of the image reconstructed with stimulated scattering changed accordingly, obeying equation (1).

The experimental relationships receive an explanation if the distribution of the power density of the exciting light inside the scattering space is taken into account (cf. fig 3). SRS is excited chiefly at the focal point of the lens in the region of the zero component of the Fourier spectrum of the object exposed to the laser radiation. The majority of the energy (approximately 80 percent) of the laser radiation is concentrated in this region. The remainder of the energy (approximately 20 percent) falls to the share of higher-order harmonics which construct in the image plane the outlines of the screen. If the pumping power density is great and the medium is sufficiently optically homogeneous, only the outlines of the screen remain in the image plane at the pumping wavelength. The intense zeroth order is absent because of its conversion into SRS.

Higher-order harmonics which are weak in intensity are not converted into SRS. Higher-order harmonics appear in the spectrum of the reconstructed image with SRS as the result of the diffraction of SRS light in amplifying absorption holograms recorded in the medium as the result of the modulation of amplification by the pumping field near the windows of the cell, where the power density of the exciting radiation is lower than the amplification saturation level. The effect of reconstruction of the image in the SRS beam disappears with saturation of amplification in these layers.

The thickness of the layer of effective diffraction and the energy range for the existence of effects depend on a number of causes. The degree of optical inhomogeneity of the medium has important value in addition to saturation of amplification. An experimental comparison was made of the thickness of layers of effective diffraction in media differing considerably in degree of optical inhomogeneity: in a single crystal of calcite (of the "extra" grade for Glan prisms), cooled to the temperature of liquid nitrogen, and in liquid nitrogen.

An experimental comparison of the localization in space and of the magnification of an image reconstructed with SRS made it possible to establish that in a medium with a high degree of optical homogeneity (a single crystal of calcite) the thickness of the layer of effective diffraction (10 to 15 cm) is considerably greater than the thickness of the layer of effective diffraction in liquid nitrogen (2 to 5 cm) under the same experimental conditions. In a medium with a high degree of optical homogeneity reconstruction of the wavefront of light takes place both in the "forward" and in the "backward" direction, in close energy ranges. In a medium which is essentially optically inhomogeneous (liquid nitrogen) reconstruction of the wavefront of light by "forward" SRS takes place over a pumping energy range which is considerably narrower than in calcite and than with "backward" SRS in liquid nitrogen. When light passes through an optically inhomogeneous medium the SRS and pumping wavefront are considerably distorted because of scattering in inhomogeneities.

Reconstruction takes place fairly effectively with "backward" SRS. On one hand, the pumping interference field is not yet distorted near the inlet window as a consequence of conversion of the light into stimulated scattering, and on the other at a certain depth of the medium the amplification of SRS at pumping intensity maxima with counter beams, with propagation of SRS "backward" toward the inlet window, compensates pumping distortions.

3. "Inversion" of Wavefront of Light in Stimulated Raman Scattering

Experience has shown that under certain conditions (thickness of the layer, illumination, sufficient optical homogeneity of the medium) the phenomenon of reconstruction of the wavefront of light takes place with "forward" and "backward" SRS. The wavefront of "forward" SRS with a certain degree of accuracy reproduces the wavefront of the laser radiation striking the medium. The wavefront of "backward" SRS is "inverted" also with some degree of accuracy (complex conjugate) relative to the wavefront of the exciting laser radiation striking the cell with the scattering substance. It is possible to observe the orientation of wavefronts with "forward" and "backward" SRS if an asymmetric object is placed in the beam of exciting laser radiation (cf. fig 4). It is obvious from this figure that the image reconstructed in a "forward" SRS beam is oriented the same as the real image of the object in the pumping beam obtained by means of the lens focusing the laser radiation on the substance. The "reflection" from the medium differs radically from reflection from an ordinary plane mirror, but is similar to reflection from a holographic mirror [10] (cf. fig 4). When laser radiation is aimed at the cell with the substance, then the laser excites SRS "backward" so that the exciting incident beam and the "reflected" almost coincide. In the plane of the image reconstructed with SRS in reflection from the cell's window, amplitude modulation is observed corresponding to a virtual inverted image of the object. In "reflection" from the medium the real image is reconstructed, oriented precisely the same as the object. That is, the wavefront with "backward" SRS is with a certain degree of accuracy the complex conjugate of the incident wavefront. Nevertheless, the difference in scale and the mismatch in space of the SRS and pumping wavefront depend quite considerably also on the difference in wavelengths of the exciting and scattered light and on a number of other factors. In this connection, the usual methods of analyzing fronts by means of a phase element, employed in dynamic holography [11], are not applicable to SRS. For example, when a glass plate etched in hydrofluoric acid is positioned near the lens its image in the SRS beam is shifted by 5 to 10 cm for the media studied. The obtainment under these conditions of data on SRS identical to data on SBS [12] testifies to the unsuitability of this procedure for studying reconstruction of the wavefront with SRS. In particular, by employing the procedure in [12] it is impossible to discover the holographic nature of the phenomenon and to determine the difference between the SRS wavefront and the pumping wavefront. The distinctive orientation of the image in "reflection" from the medium can be used as a convenient method of separating scattered light from that reflected from the windows of the cell with the substance or from the faces of the crystal. This method is especially convenient with a slight shift in the frequency of scattered light (SBS, SRS) relative to the exciting light.

It is possible to draw a conclusion regarding the degree of reproduction of the wavefront of the light in stimulated scattering on the basis of analyzing the parameters (magnification and contrast) of the image reconstructed in SRS.

Experience has shown that the degree of accuracy of reproduction of the wavefront depends both on the parameters of the medium (dielectric constant and optical homogeneity) and on excitation conditions (thickness of the medium's layer, pumping energy, illumination configuration, pulse length). For example, since the contrast of the interference pattern in the medium depends nonlinearly on the pumping power, then the contrast of the image in the SRS beam varies with the pumping power density. When SRS was excited by means of a pulse of nanosecond length [13] in a layer of cyclohexane of uniform thickness, a change in power from 15 to 50 MW/cm^2 resulted in a change in contrast and the magnification of the image reconstructed in SRS changed threefold. In a word, optimum experimental conditions exist under which reconstruction of the wavefront of light with SRS is shown to be most complete. A necessary condition for this reconstruction, as demonstrated experimentally, is the existence of directed zeroth-order diffraction (close in terms of directivity to the laser radiation) and the presence in the medium of a layer playing the role of a dynamic hologram. Of interest for practical applications is not only total reconstruction of the wavefront, but also the ability to filter frequencies in the object's spectrum by methods of nonlinear optics. Realization of this filtering is possible in principle with the reconstruction of wavefronts of light in media which are active in stimulated scattering.

In this study a qualitative model of the phenomenon of reconstruction of the wavefront of light with SRS is discussed, making it possible to explain all the key relationships observed experimentally. At the present time theoretical studies exist [14-17] in which several aspects of the reconstruction phenomenon are explained, but a number of certain important experimental factors contradict the explanations suggested. For example, in [13] the mode theory of volume holograms, developed in [17], is used to explain reconstruction of a wavefront with SRS. According to [13] the reconstruction effect can be observed with a shift in the frequency of the scattered light no greater than 2000 cm^{-1}. In experiments reconstruction is observed with considerably greater frequency shifts and the experimental limit of the shift with which reconstruction takes place has yet to be reached. The feature of the distribution of illumination within the medium in the excitation of SRS under superluminous emittance conditions simultaneously with the saturation effect has also not been taken into account in a single theoretical study.

It must be mentioned that in principle the wavefront of light can be recorded by the recording in a medium, active in SRS, of mixed amplitude-phase holograms. Recording can involve not only modulation of amplification, but also the change in the real part of the dielectric constant, i.e., the refractive index [7, 18]. The refractive index can vary under the influence of laser radiation on account of the high-Q Kerr effect, electrostriction, a change in the polarizability of molecules during excitation, etc. Essentially the same causes result in another effect--the self-focusing of light.

4. Self-Focusing of Stimulated Raman Scattered Light

Experimental studies of a wide range of substances with various optical characteristics and probabilities of Raman scattering of light have demonstrated that the pattern of the development of self-focusing of light observed in media with a large effective Raman scattering cross section differs radically from the generally accepted ideas.

In media with a large effective Raman scattering cross section the power density of radiation required for reaching the self-focusing threshold is achieved considerably sooner in the SRS beam than in the beam of exciting laser radiation [1, 19].

This occurs as a consequence of two main causes: 1) the exponential law for the amplification of SRS results in reduction of the diameter of the SRS beam and in an increase in its brightness and coherence in propagation in the space bounded by the pumping beam with a distribution of intensity which diminishes from the center to the edges; 2) the power of the exciting laser radiation decreases first of all in regions of maximum intensity when it is converted into SRS. The conversion factors can reach 60 to 70 percent. In this connection, the power required for self-focusing is reached sooner in the SRS beam than in the laser radiation beam.

Self-focusing in the SRS and laser radiation beams develops independently, separately from one another [20, 21]. Self-focusing conditions (the number and dimensions of focal regions) in the SRS beam depend solely on the power of the laser radiation converted into SRS [3, 21].

The experimental results cited could not be explained on the basis of ideas regarding the excitation and propagation of SRS in threads of self-focusing of laser light. The new multifocal pattern of the propagation of light beams in media with Kerr nonlinearity suggested in [22, 24] eliminated a great number of contradictions between theory and experimental results [23]. According to [22, 24], with high conversion factors, because of the coherence of the SRS beam, an independent focal structure forms in it, independent of the multifocal structure of the exciting radiation. Aspects of the angular spectral and time distribution of the intensity of SRS under conditions when the main SRS energy is concentrated in regions of the self-focusing of SRS light found an explanation. An explanation was found for the experimental result to the effect that with an increase in SRS power focal regions in beams of SRS components, representing the vertices of radiation cones, and of higher-order Stokes and anti-Stokes components, draw near the outlet window of the cell, whereby the opening of the cones increases smoothly right up to values exceeding angles of the Cerenkov type [20].

5. Conclusion

The results of studies have shown that substances which are active in stimulated Raman scattering can be divided into three groups [3]. Group A: substances with a high Kerr constant ($K \simeq 20$ CGSE units), high gain ($g \simeq 1$ MW/cm^2) and a high ratio of SRS energy under saturation to the energy of the laser radiation ($E_s/E_0 = 10^{-1}$). Group B: K is close to zero, $g \simeq 0.1$ MW/cm^2 and $E_s/E_0 \simeq 10^{-1}$. Group C: substances with a low Kerr constant of $K \simeq 10$ CGSE units, and values of $g \simeq 0.01$ MW/cm^2 and $E_s/E_0 \simeq 10^{-2}$ to 10^{-3}. Substance of types A and B, having high values of g and E_s/E_0, in spite of the great difference in Kerr constants, have common properties. Focal regions measuring 10 microns are observed in an SRS beam with its maximum intensity. Characteristic of these substances is a sudden change in intensity when a certain value of the gain increment is reached. However, a great number of properties are different for substances of types A and B. Their Kerr constants differ markedly, the power density and total energy concentrated in focal regions of minimum diameter are much less in substances of type B, and the ratio of SRS thresholds for exciting radiation with circular and linear polarization is different. The identical small-scale focal structure of SRS in substances of types A and B and, at the same time, considerable differences in a number of important properties, make it possible to suggest that the key mechanisms responsible for a change in the real part of polarizability in media of these types can be different. The theoretical estimates in [25] and comparisons with experimental data in media with low Kerr constants give results in favor of a mechanism involving a change in the polarizability of molecules during excitation [19, 26]. In substances of type C self-focusing points 10 microns in diameter originate. The manifestation of a small-scale focal structure in the SRS beam is characteristic of substances with a high value of the factor for the conversion of laser radiation into SRS. In media of group A, where the concentration of intensity in self-focusing regions is especially high, the multifocal structure in the SRS beam destroys the effect of reconstruction of the wavefront of light in SRS. The effect exists only over a small energy range. If with the same value of E_s/E_0 the gain is not very high, the energy range for the existence of reconstruction is expanded. Reconstruction of the wavefront with stimulated scattering is observed over a considerably broader excitation energy range in media of groups B and C than in media of group A.

Thus, optimum values exist for the gain of the conversion of light into SRS and for values of the nonlinear contribution to the refractive index with which the effect of reconstruction of the wavefront is observed over a broad energy range and the self-focusing of light does not destroy the reconstruction. The relationships gotten for stimulated Raman scattering are of a general nature and are valid for any nonlinearly amplifying media.

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POSSIBLE AND IMPOSSIBLE IN DIGITAL HOLOGRAPHY

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[Text] An analysis is made of the limiting characteristics of the accuracy of solving primal and inverse problems of digital holography. The relationship between the limiting accuracy of reconstructing the parameters of an object and the characteristics of the recording and hologram digital processing systems is established. Analytical expressions and numerical estimates are obtained for the limiting accuracy of the reproduction of wavefronts as a function of errors in the digital representation of holograms on a computer.

1. Introduction

Digital holography in the last 10 years has attracted the attention of an ever greater number of investigators--physicists, mathematicians and engineers. A number of generalizing surveys have appeared [1, 2] and a monograph [3] reflecting the state of the art of the problem of analyzing and synthesizing wave fields on a computer. But hitherto estimates of the practical capabilities of digital holography have been very contradictory. Optimists (among which the authors of this article are numbered) believe that digital holography in combination with physical will make it possible to solve a number of important scientific and applied problems from the number of "insoluble" ones. Skeptics not without justification point to the quite modest practical successes of modern digital holography and express doubts about their possible growth. In this situation the decisive role belongs to the theory of digital holography, but its creation has encountered a number of fundamental difficulties associated primarily with the need to change from qualitative estimates--"worse" or "better"--to quantitative criteria for comparing the various methods of analyzing and synthesizing holograms on a computer, as well as with the need to establish some limiting values for these criteria. Clearly realizing the hopelessness of attempting to construct a general theory of digital holography at the present time, the authors have attempted, nevertheless, in this article, having narrowed the class of problems discussed, to introduce the required quantitative criteria and to establish their limiting values. It was possible to conduct an investigation of the limiting characteristics of the accuracy of synthesizing holograms on a computer (the primal problem of digital holography) for problems of testing optical surfaces and the spatial filtering of optical fields. The discussion carried out made it possible to indicate the limits of the parameters of wavefronts permitting synthesis by methods of digital holography. An investigation of the limiting characteristics of the accuracy of reconstructing images and of their parameters (the inverse problem of digital holography) was performed for Fresnel-Fraunhofer holograms and holograms of phase objects.

2. Limits of the Possible for Holograms Synthesized on a Computer

Even the first investigators [4] discovered that an image reconstructed from a computer hologram is of rather poor quality, sometimes even little like its mathematical description. To understand the reasons for these distressing results, it is necessary to discuss in greater detail the process of producing a computer hologram. Here we will consider errors specific only to computer holograms per se, without taking into account the influence of the recording medium and other factors which appear in physical holograms also. Let it be required to produce a hologram with an amplitude transmission function of $W(u, v)$, where $|u| \leq d/2$ and $|v| \leq d/2$ (where d is the dimension of the hologram).

Only $N \times N$ samples of the hologram are stored in the computer,

$$\Gamma_{nm} = Q_M[W(u_n, v_m)]; \quad n,m = \overline{1,N}, \tag{1}$$

obtained from the "mathematical" hologram, $W(u, v)$, by sampling with an interval of δ and by quantizing with M levels (Q_M denotes the sample quantization operation). Let us note that quantity δ is the resolution of a computer hologram.

Quantities $\{\Gamma_{n,m}; n,m = \overline{1,N}\}$ are supplied in the form of electrical signals to a hologram recording unit which exposes to light $N \times N$ cells on the surface of a light-sensitive medium with an exposure determined by the individual sample, or which modulates a beam of coherent light. Sampling appears to be a completely "legitimate" operation in view of the familiar sampling theorem. However, this is true only at first glance. In reality sampling operations result in the manifestation of basic differences between computer holograms and physical holograms and considerably restrict the class of "realizable" wavefronts which can be reconstructed from computer holograms with errors acceptable for practical applications.

It is generally not possible to indicate the class of realizable wavefronts. However, there is a broad class of problems in which a wavefront reconstructed from a synthesized hologram is used for quantitative measurements and optical computations. This class includes the optical spatial filtering of an image, the testing of optical systems by means of synthesized holograms and a number of other problems. Present in explicit form in these problems is not only the mathematically assigned structure and form of the wavefront which must be produced, but also a quantitative criterion for the accuracy in producing it.

Let us consider the problem of producing a reference aspherical wavefront, σ (cf. fig 1). Let the hologram, Γ , be synthesized so that when it is exposed to beam B (usually spherical or plane) at a specified distance the aspherical wavefront, σ , must be reconstructed. In consequence of the finite dimension of the hologram, d , the finite resolution of the hologram, δ , and the limited number of samples, $N = [d/\delta]$, and quantization levels, M , instead of the wavefront, σ , only a front close to it, $\hat{\sigma}$, is reconstructed (cf. fig 1). The maximum (ε_{max}) or standard ($\bar{\varepsilon}$) deviation of front $\hat{\sigma}$ from σ is the criterion for the accuracy of synthesis of hologram Γ . Quantities ε_{max} and $\bar{\varepsilon}$ depend, first, on the parameters of front σ (diameter, D , radius of curvature, R , degree of asphericity and the like) and, secondly, on the parameters of the hologram recording unit (resolution, δ , or number of samples, N , diameter of the hologram, d , number of quantization levels, M):

$$\varepsilon_{max} = \varepsilon_{max}(\delta, d, M;\ \mathcal{D}, R, \ldots) = \varepsilon_{max}(N, d, M; \mathcal{D}, R, \ldots).$$

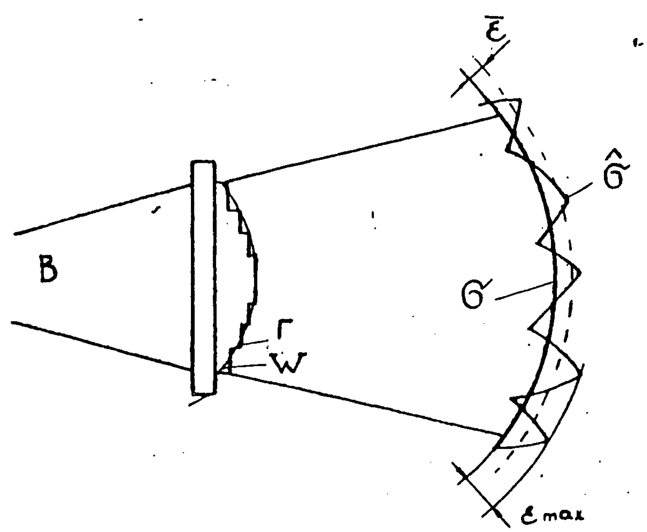

Figure 1. Producing Reference Wavefront by Means of Hologram Synthesized on Computer

If error ε_{max} turns out to be too great, then it is impossible to produce front σ by means of hologram Γ . Thus, in this problem the "region of the impossible" is determined by the relationship

$$\varepsilon_{max}(N, d, M;\ R, \mathcal{D}, \ldots) \geqslant \varepsilon_{gon}, \tag{2}$$

where ε_{dop} is the permissible maximum error. For broad applications, $\varepsilon_{dop} = \lambda/5$, where λ is the wavelength of the light.

In especially precise optical devices $\varepsilon_{dop} = \lambda/10$ to $\lambda/100$. Equation (2) with assigned characteristics of the computer hologram recording unit defines a certain region of values of parameters of front σ. Wavefronts with parameters from this region cannot be realized by methods of digital holography (when using devices with the characteristics N, d and M).

Example 2.1.

Let reconstructing front B, spherical with a center of 0, be at a distance of R from the vertex of the aspherical surface of σ, assigned by the equation

$$z = f(\rho) = R - \frac{\rho^2}{2R} + f_4\rho^4 - f_6\rho^6 + \dots \tag{3}$$

(cf. fig 2). Then it is possible to show that accuracy ε_{max} is determined from the equation

$$\varepsilon_{max} = \frac{\lambda}{2M} + \frac{\lambda d^4\sqrt{2}}{64\pi N}\left(8\varphi_4 - 3d^2\varphi_6 + \dots\right), \tag{4}$$

where

$$\varphi_4 = \frac{2\pi}{\lambda}\frac{1}{a^4}\frac{R}{8}\left(1 + 8R^3 f_4\right), \tag{5}$$

$$\varphi_6 = \frac{2\pi}{\lambda}\frac{1}{a^6}\left[\frac{R(R+a)}{8a} + \frac{R^3(4R^2 - 5aR + 24a^2)}{2a} f_4 + \right. \tag{6}$$

$$\left. + \frac{8(R-a)(13R-16a)}{a} f_4^2 + 120a(2R-3a)R^4 f_6\right],$$

$$a = f\left(\frac{\mathcal{D}}{2}\right) + \frac{\mathcal{D} - d}{2f'\left(\frac{\mathcal{D}}{2}\right)} \quad - \tag{7}$$

is the distance from the hologram to point source 0 of the spherical wave. In particular, for a parabolic wavefront with a focal length of F_0 we have $R = 2F_0$, $f_4 = f_6 = \dots = 0$, and it is possible to obtain the simple estimate:

$$\varepsilon_{max} \cong \frac{\lambda}{2M} + \frac{\sqrt{2}}{256}\frac{1}{N}\frac{\mathcal{D}^4}{F_0^3}. \tag{8}$$

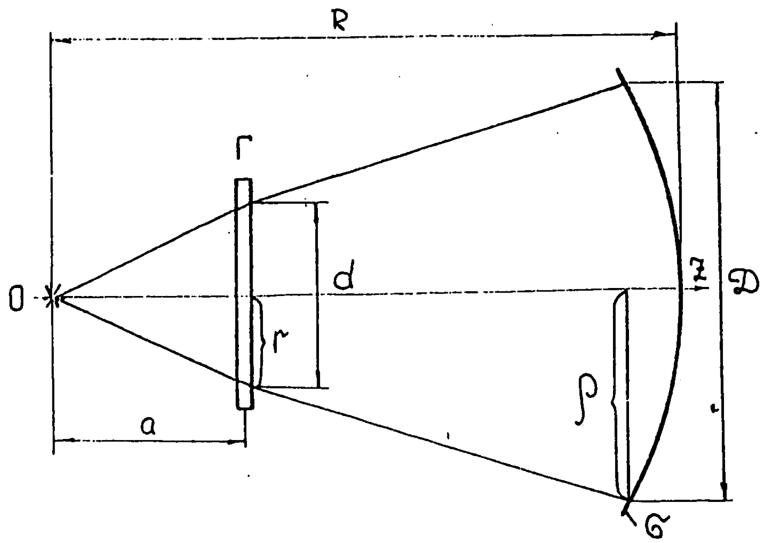

Figure 2. Conversion of Spherical Wavefront into Aspherical Front

The region of the impossible (2) is the region of values of parameters (F_0 , D) for which

$$\frac{D^4}{F_0^3} \geqslant 128\sqrt{2}\, N \left(\varepsilon_{gon} - \frac{\lambda}{2M}\right). \tag{9}$$

The boundary of the region is the curve

$$D = 2\sqrt[4]{8\sqrt{2}\, N F_0^3 \left(\varepsilon_{gon} - \frac{\lambda}{2M}\right)}\,. \tag{10}$$

In fig 3 the hatching represents the region of values of the focal length, F_0 , and diameter, D , of the front which is impossible to realize with accuracy of ε_{dop} = = $\lambda/20$ by means of methods of digital holography when using a hologram recording unit with N = 1024 and M = 256 . The cross-hatched area designates the region corresponding to $\varepsilon_{dop} = \lambda/5$.

It is possible to select the hologram recording unit by using table 1, in which the values of error ε_{max} are given as a function of the resolution, $\delta = d/N$, with various diameters of the wavefront (F_0 was selected at 500 mm, d = 25.6 mm , M = 256 and $\lambda = 0.6328$ μ).

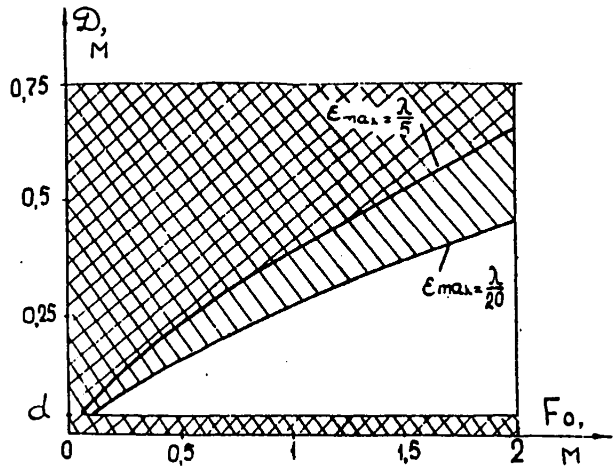

Figure 3. Region of Values of Diameter and Focal Length of Parabolic Wavefront Which Cannot Be Produced with Accuracy of $\lambda/20$ (Hatched Area) and $\lambda/5$ (Cross-Hatched Area) from Spherical Wavefront When Using Unit with Number of Samples of $N = 1024$ and Quantization Levels of $M = 256$

Table 1.

D \ δ	50 мкм (1)	25 мкм	I2 мкм	5 мкм	I мкм
200 мм	$\frac{\lambda}{4,5}$	$\frac{\lambda}{9}$	$\frac{\lambda}{18}$	$\frac{\lambda}{42}$	$\frac{\lambda}{160}$
300 мм	$\frac{\lambda}{1,5}$	$\frac{\lambda}{3}$	$\frac{\lambda}{6}$	$\frac{\lambda}{14}$	$\frac{\lambda}{65}$

Key:
1. μ

Another problem in which synthesized spatial filters are used is the generalized spectrum analysis of an image, $\xi(x,y)$, $|x| \leq A$, $|y| \leq A$, $A = d/2$, consisting in the computation of L first coefficients,

$$\xi_k = \int_{-A}^{A}\int_{-A}^{A} \xi(x,y)\Psi_k^*(x,y)\,dx\,dy\,; \qquad k = \overline{1,L} \tag{11}$$

of expansion of the image according to an orthonormalized system of basis functions, $\{\psi_k(x,y)\}^L$ (* is the complex conjugation symbol).

The use of computers linked by means of recording units in principle opens up the possibility of implementing complex basis functions in the form of a set of synthesized spatial filters. However, the above-named sampling errors in the synthesis of filters on a computer result in "perturbed" basis functions, $\phi_k(x,y) = \psi_k(x,y)$, and in errors in computing coefficients, i.e., actually instead of (11) "perturbed" coefficients are computed:

$$\zeta_K = \int_{-A}^{A}\int_{-A}^{A} \xi(x,y)\,\varphi_K^*(x,y)\,dx\,dy\ ; \quad K=\overline{1,L}\,. \tag{12}$$

With the improper selection of the number of L terms, depending on the characteristics of the recording unit (N , M , A) and the parameters of the image, $\xi(x,y)$, coefficients ζ_k will differ so much from ξ_k that it will be necessary to refrain from using spatial filters synthesized on a computer. It is possible to choose as a criterion for the accuracy of synthesized spatial filters the error of generalized spectrum analysis by means of these filters, i.e., the value, ε^2 , of the standard deviation from the image, $\xi(x,y)$, of a segment of L first terms of its orthogonal expansion. Let us note that error ε^2 is determined not by a single hologram, but by an entire set of L spatial filters. The maximum permissible minimum value of error ε^2 is made possible by means of an optimum Karunen-Loew basis. In [5] it is demonstrated that for Karunen-Loew basis functions

$$\varepsilon^2 = \varepsilon_d^2(L) + \varepsilon_h^2(L) + \varepsilon_o^2(L). \tag{13}$$

Component $\varepsilon_d^2(L)$ characterizes representation of the image by a finite number of L generalized spectral components with the ideal implementation of Karunen-Loew basis functions. Obviously, $\varepsilon_d^2(L)$ diminishes monotonically with an increase in L . With the digitization of basis functions error ε^2 is higher than $\varepsilon_d^2(L)$ and the errors of basis functions accumulate with an increase in L and are characterized by quantity $\varepsilon_h^2(L)$ and $\varepsilon_0^2(L)$. An excessive increase in number L with the existence of inaccurately implemented (quantized) basis functions is not sound and results not in an improvement but in worsening of accuracy. Thus, in the implementation of basis functions by methods of digital holography it is impossible to obtain accuracy better than $\varepsilon_d^2(L)$.

Example 2.2.

Let the image, (x,y) , have a biexponential correlation function,

$$R(\Delta x, \Delta y) = \sigma^2 \exp\left(-\frac{\nu_x}{A}|\Delta x| - \frac{\nu_y}{A}(\Delta y)\right) \tag{14}$$

whereby in dimension d of the image $v_x = v_y = v$ correlation intervals are placed along axes x and y , respectively.

Plots of the dependence of error ε^2 on the number of coefficients, L , with different numbers of samples of the spatial filter implementing the basis function ($v_x = v_y = 2.3$) are given in fig 4. The dotted line indicates the maximum value of the accuracy which can be approached with $N \to \infty$. It is obvious from fig 4 that with any finite N curve $\varepsilon^2 = \varepsilon^2(L)$ has a minimum at point $L = L_0(N)$. It is inadvisable to increase L to values higher than $L_0(N)$, since because of the accumulation of basis function errors the accuracy all the same will not be better than the limiting value of $\varepsilon^2(L_0(N))$. With an increase in the number of samples, point $L_0(N)$ shifts to the right and the maximum achievable error, $\varepsilon^2(L_0(N))$, is reduced. Simultaneously with an increase in N error ε^2 is reduced with each L .

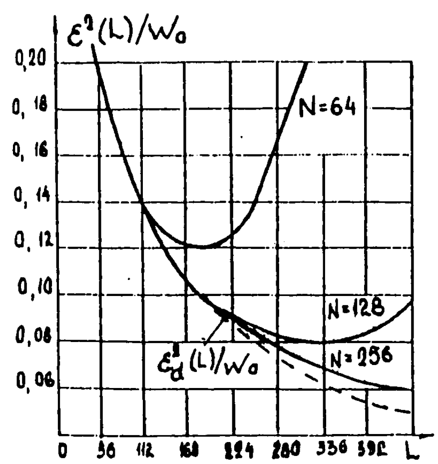

Figure 4. Mean Square Error of Generalized Spectrum Analysis of Image with Implementation of Basis Functions in Form of Spatial Filters Synthesized on Computer

Values of ε^2 relative to the total energy of the image, W_0 , with L = 456 , $v_x = v_y = 2.3$, for various numbers of samples, N , are given in table 2.

Table 2.

N	128	256	512	1024
$\frac{\varepsilon^2}{W_0}$	9,8%	5,8%	5,5%	5,4%

Table 2 and the graph in fig 4 make it possible to determine the number of samples of the spatial filter for a prescribed class of accuracy.

3. Limits of Accuracy of Reconstruction of Parameters of an Object from a Hologram

A holographic experiment makes it possible to record complex fields and to reconstruct an object. In the final analysis investigators are interested either in the parameters of the studied object (e.g., the geometrical dimensions and coordinates of parts of the image), or in the image of the object per se. We know [6] that at the stages of recording and reconstructing the hologram accidental distortions originate which reduce the accuracy of measuring the parameters of the image. In information theory methods are known which make it possible to estimate the limiting accuracy of the reconstruction of parameters for certain observation models [7, 8]. Therefore, the problem arises of developing models for the observation of signals corresponding to various arrangements of the holographic process.

In estimating the accuracy of measuring parameter a of the holographic image we will use the mean square error

$$\sigma^2 = E(\hat{a} - a)^2, \tag{15}$$

where E is the averaging operator and $(\hat{a} - a)$ is the error in measuring the parameter.

The error in measuring the holographic image of an object, $u(\vec{x})$, is determined by the expression

$$\varepsilon^2 = E\left\{\int_X [\hat{u}(\vec{x}) - u(\vec{x})]^2 d\vec{x}, \tag{16}$$

where $\hat{u}(\vec{x})$ is the image of the object placed in region $\vec{x} \in X$.

We will also use the relative mean square errors

$$\delta^2 = \sigma^2 / a^2 \tag{17}$$

$$e^2 = \varepsilon^2 / \sigma_u^2, \tag{18}$$

where σ_u^2 is the variance of image $u(\vec{x})$.

The simplest observation model has the form:

$$z(\vec{x}) = a \cdot s(\vec{x}) + n(\vec{x}), \quad \vec{x} \in X, \tag{19}$$

where a is the unknown amplitude of the signal, $s(\vec{x})$ is a determinate function and $u(\vec{x})$ is Gaussian white noise with a spectral power density of N_0.

The mean square error in estimating parameter a from model (19) is

$$\sigma^2 = N_0 \left(\int_X s^2(\vec{x})\, d\vec{x} \right)^{-1}. \tag{20}$$

If the measured parameter enters the observed field nonlinearly, then the model has the form

$$z(\vec{x}) = s(\vec{x}, a) + n(\vec{x}), \quad \vec{x} \in X, \tag{21}$$

and the accuracy of reconstruction has a lower limit determined by the Cramer-Rao inequality [7]:

$$\sigma^2 \geq N_0 \left(\int_X \left[\frac{\partial s(\vec{x}, a)}{\partial a} \right]^2 d\vec{x} \right)^{-1} \tag{22}$$

If in (21) function $s(\vec{x},a)$ is random, then the accuracy of reconstructing parameter a has the following lower limit [8]:

$$\sigma^2 \geq N_0^2 \left(\frac{1}{2} \iint_{X\,X} \left[\frac{\partial K_s(\vec{x}_1, \vec{x}_2, a)}{\partial a} \right]^2 d\vec{x}_1\, d\vec{x}_2 \right)^{-1}, \tag{23}$$

where

$$K_s(\vec{x}_1, \vec{x}_2, a) = E\left\{ s(\vec{x}_1, a)\, s(\vec{x}_2, a) \right\}. \tag{24}$$

Relationship (23) is valid when

$$\lambda(0) \ll N_0, \tag{25}$$

where $\lambda(\omega)$ is the energy spectrum of random signal $s(\vec{x},a)$.

For the image observation model

$$z(\vec{x}) = u(\vec{x}) + n(\vec{x}), \quad \vec{x} \in X = \infty \tag{26}$$

we get

$$\varepsilon^2 = \int_{-\infty}^{\infty} \frac{N_0 G(\vec{\omega})}{N_0 + G(\vec{\omega})} d\left(\frac{\vec{\omega}}{2\pi}\right). \tag{27}$$

In (26) and below it is assumed that stationary field $u(\vec{x})$ has an energy spectrum of $G(\vec{\omega})$. It is convenient to write a model with linear distortion in the spectral region

$$Z(\vec{\omega}) = H(\vec{\omega}) U(\vec{\omega}) + N(\vec{\omega}), \tag{28}$$

where $H(\vec{\omega})$ is the transfer function of the distorting filter. The mean square error for (28) was determined in [9]:

$$\varepsilon^2 = \int_{-\infty}^{\infty} \frac{N_0 G(\vec{\omega})}{N_0 + |H(\vec{\omega})|^2 G(\vec{\omega})} d\left(\frac{\omega}{2\pi}\right). \tag{29}$$

If transfer function $H(\vec{\omega})$ in model (28) is random, then

$$Z(\vec{\omega}) = [H_0(\vec{\omega}) + \tilde{H}(\vec{\omega})] U(\vec{\omega}) + N(\vec{\omega}), \tag{30}$$

where $\tilde{H}(\vec{\omega}) = H(\vec{\omega}) - H_0(\vec{\omega})$ is a random (unknown) component of the spatial filter.

It is demonstrated in [10] that under certain conditions the reconstruction error for (30) has the form

$$\varepsilon^2 = \int_{-\infty}^{\infty} \frac{[N_0 + G(\vec{\omega}) G_H(\vec{\omega})] G(\vec{\omega})}{N_0 + G(\vec{\omega}) G_H(\vec{\omega}) + |H_0(\vec{\omega})|^2 G(\vec{\omega})} d\left(\frac{\vec{\omega}}{2\pi}\right), \tag{31}$$

where

$$G_H(\vec{\omega}) = E\{|\tilde{H}(\vec{\omega})|^2\}$$

is the energy spectrum of the error of the spatial filter.

Let us note that model (30) can be used for describing the quantizing and sampling processes when entering a hologram or holographic image into a computer.

In the examples below we specify the observation model described above for certain arrangements of a holographic experiment.

Example 3.1. Use of Fraunhofer Holograms for Measuring Velocities of Microparticles

In [11] a method is described for measuring the mean velocity of particles from an interference pattern in a Fraunhofer plane produced during double exposure. The Fraunhofer diffraction pattern reconstructed from the hologram has a periodic structure which for a unidimensional Gaussian distribution of velocities has the form:

$$S(x,a) = B(x)\left[1 + \cos(ax)\exp\left(-\frac{\sigma^2}{2}x^2\right)\right], \tag{32}$$

where a is the measured quantity proportional to the mean velocity of microparticles, σ^2 is the variance in velocities of microparticles, $B(x)$ is a structure function determined by the form and orientation of microparticles (for analysis we assume that $B(x) = B$). It is easy to see that (32) corresponds to model (21):

$$\int_{-\infty}^{\infty}\left(\frac{\partial s}{\partial a}\right)^2 dx = B^2\int_{-\infty}^{\infty} x^2 \sin(ax)\exp(-\sigma^2 x^2)dx = \frac{B^2\sqrt{\pi}}{4\sigma^3}. \tag{33}$$

In (33) we assume that the region of analysis is unlimited ($x \to \infty$), and that $a/\sigma \gg 1$. Using (22) and (17) we get

$$\delta_a^2 \geq \frac{4N_0\sigma^3}{B^2\sqrt{\pi}a}. \tag{34}$$

Let us note that the use of appropriate methods of signal processing [7] makes it possible also to estimate parameter σ^2 .

Example 3.2. Estimate of Diameter and Coordinates of Center of Particle

The intensity of the holographic image of a round particle can be described approximately by means of a Gauss spot:

$$s(x,y,a,x_0,y_0) = A\exp\left[-\frac{(x-x_0)^2+(y-y_0)^2}{2a^2}\right], \tag{35}$$

where a is the diameter of the particle and $(x_0 y_0)$ represents the coordinates of the center of the particle. Using (22), we get

$$\begin{cases} \sigma^2_{x_0(y_0)} \geq \dfrac{2N_0}{\pi A^2}, \\ \delta_a^2 \geq \dfrac{N_0}{2\pi A^2 a^2}. \end{cases} \tag{36}$$

Let us note that the limits of the accuracy of determining the coordinates of the center of the particle do not depend on its diameter.

Example 3.3. Multiplicative Noise

For the sake of simplicity let us consider a unidimensional model of observation of a particle:

$$z(x) = \sqrt{P} \exp\left(-\frac{x^2}{2a^2}\right) \varphi(x) + n(x), \tag{37}$$

where $\phi(x)$ is a random function describing the multiplicative noise of the holographic process (e.g., the diffuse noise). Equation (37) agrees with model (21) with a random signal of $s(x,a)$ with correlation function (24) of the form

$$K_s(x, y, a) = P\sigma_\varphi^2 \exp\left[-\frac{x^2+y^2}{2a^2} - \frac{(x-y)^2}{b^2}\right]. \tag{38}$$

With $a/b \gg 1$ from (22) and (38) we get

$$\delta_a^2 \geqslant \frac{16 N_0^2}{3\pi P^2 \sigma_\varphi^4 b a}. \tag{39}$$

Let us note that the limit of the relative mean square error is inversely proportional to the correlation distance of multiplicative noise.

Example 3.4. Accuracy of Reconstruction of Image

Let us determine the mean square error in observation of an image against a background of additive noise--model (26). We will discuss the three most widespread classes of images corresponding to the following correlation functions: 1) biexponential, 2) exponential isotropic and 3) Gaussian isotropic.

Using (16) and (18) we get

$$e_1^2 = \frac{2}{\pi}\left(1+\frac{2}{\pi}\Lambda\right)^{-1/2} K\left[\left(1+\frac{\pi}{2\Lambda}\right)^{-1/2}\right], \tag{40}$$

$$e_2 = \frac{1}{6\Lambda} \ln\frac{(1+\Lambda)^2}{1-\Lambda+\Lambda^2} + \frac{1}{\Lambda\sqrt{3}} \operatorname{arcctg}\frac{2-\Lambda}{\Lambda\sqrt{3}}, \tag{41}$$

$$e_3 = \frac{2}{\Lambda} \ln\left(1+\frac{\Lambda}{2}\right). \tag{42}$$

Here Λ is the signal-to-noise ratio and K(•) is a complete elliptic integral of the first kind. Relationships (40), (41) and (42) are presented in fig 5.

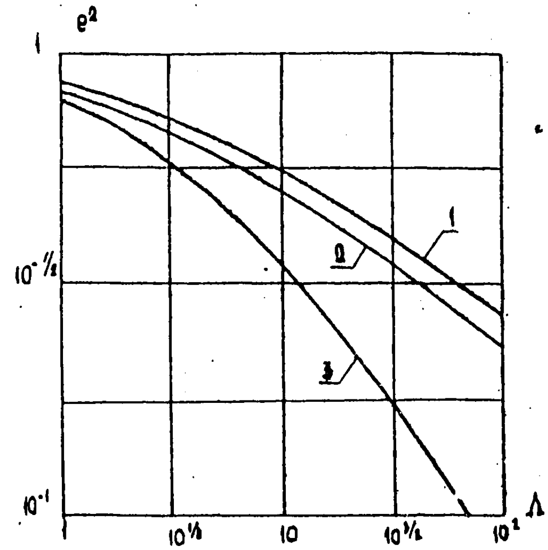

Figure 5. Limit of Mean Square Error in Reconstruction of Image with Correlation Functions: 1--Biexponential, 2--Exponential Isotropic, 3--Gaussian Isotropic

In conclusion we get the limit of the accuracy of reconstruction of holographic images with a Gaussian isotropic correlation function with a correlation distance of $1/\alpha$ taking into account the limited angular dimension, 2Ω, of a Fraunhofer hologram. From (29) we get

$$\varepsilon^2 = \exp(-\Pi^2) + \frac{2}{\Lambda}\ln\frac{1+\frac{\Lambda}{2}}{1+\frac{\Lambda}{2}\exp(-\Pi^2)}, \quad (43)$$

where $\Pi = \Omega/2\alpha$ is the reduced dimension of the hologram. Error (43) is illustrated in fig 6.

4. Conclusion

Further studies of the limiting characteristics of the accuracy of solving primal and inverse problems and the limits of the possible and impossible in digital holography are most urgent along the following lines:

1. Expansion of the range of applied problems studied--visualization, adaptive spatial filtering, optical systems for detecting and recognizing objects.

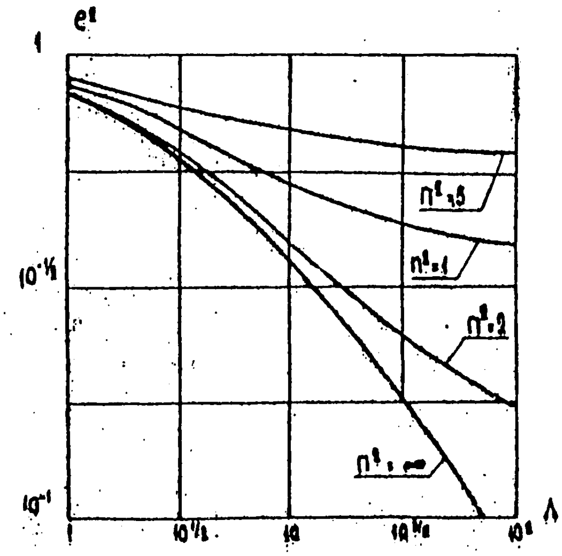

Figure 6. Limit of Mean Square Error in Reconstruction of Images with Limited Dimensions of Hologram

2. Conduction of series of experiments confirming (or disproving) theoretical estimates of the limits of the possible and impossible in digital holography.

3. Study of a broader set of equipment for digital holography--graph plotters, photolithographic units, computer-controlled space modulators, units with a controlled laser beam, etc.

4. Analysis of a broader class of holograms and interferograms.

5. Study of the implementation aspects of digital holography associated with input of machine time for solving primal and inverse problems.

The authors hope that the work done by them will attract the attention of investigators toward solving theoretical and experimental problems in digital holography already formulated and toward formulating new ones.

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8831
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DATA CONVERSION

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DATA CONVERTERS AND DATA TRANSMISSION EQUIPMENT

Kiev PREOBRAZOVATELI FORMY INFORMATSII I SREDSTVA PEREDACHI DANNYKH in Russian 1981 (signed to press 21 Apr 81) pp 2, 82

[Annotation and table of contents of book "Data Convertors and Data Transmission Equipment" edited by Doctor of Technical Sciences A. I. Kondalev, Ordena Lenina Institut kibernetiki, 600 copies, 89 pages]

[Text] Annotation

The articles in this collection review the questions of designing microelectronic data convertors and their components. The book presents an analysis of the error of data conversion equipment used in monitoring devices and measuring devices for displacements and dimensions, and investigates the dynamic characteristics of elements of analog-digital and digital-analog convertors. The hardware of data exchange systems is considered. Requirements are defined for the characteristics of receivers, concentrators, and other units of data transmission systems.

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HIGH-SPEED MICROELECTRONIC DATA CONVERTERS BASED ON BIPOLAR TECHNOLOGY

Kiev PREOBRAZOVATELI FORMY INFORMATSII I SREDSTVA PEREDACHI DANNYKH in Russian 1981 (signed to press 21 Apr 81) pp 3-8

[Article by A.-I. K. Martsinkyavichus and V. B. Abraytis from book "Data Convertors and Data Transmission Equipment" edited by Doctor of Technical Sciences A. I. Kondalev, Ordena Lenina Institut kibernetiki, 600 copies, 89 pages]

[Text] The integrated circuits of high-speed digital-analog and analog-digital convertors are applied in digital television, digital videorecording, digital processing of radar signals, digital communications systems, and in measuring and telemetric devices.

At the present time work on digital-analog and analog-digital convertors is progressing in the following areas:

1. Broadening the functional capabilities of the information systems of digital-analog convertors (DAC's) and analog-digital convertors (ADC's) by increasing their circuit and design complexity and including in them sources of reference quantities, operations amplifiers, digital interlinking circuits, and the like. In this case the number of components on a chip increases from 150-200 to 5,000-20,000 and more.

2. Increasing the precision and resolution of conversion to 14-16 bits for DAC's and 8-10 bits for ADC's with a simultaneous decrease in power consumed per bit.

3. Increasing the speed from hundreds of kilohertz to hundreds of megahertz.

4. Improving temperature stability to 10^{-6} 1/degree in the temperature range from -60 to +125 degrees C.

The distinguishing features of the development of integrated DAC and ADC circuits in comparison with digital circuits are the following:

1. The large assortment of types of components, including n-p-n and p-n-p transfers and lateral transistors, diodes, stabilitrons, and solid state and film resistors; this makes the fabrication of integrated circuits in a single industrial cycle more complex.

2. The irregular structure of the schematic electrical diagram, which makes it more difficult to formalize the structure of fabrication topology and to monitor the microcircuits.

3. Heightened requirements for the parameters and spread of parameters of the components and for the temperature and time stability of the input and output characteristics of the integrated circuits (for example, the relative error of resistors for the 12-bit 594PA1 DAC should be no more than 0.01 percent and the temperature stability of the output current should be $3 \cdot 10^{-6}$ 1/degree.)

4. Two-three times as many monitored parameters in the production cycle, final monitoring, and testing, and also high requirements for the precision of the monitoring and testing apparatus.

5. Special conditions for measurement and testing of electrical characteristics (such as the shielding of the space, the presence of a separate grounding line and special power supply sources, and so on).

In the fabrication of high-speed, highly complex DAC and ADC integrated circuits three-diffusion bipolar technology is widely used. In this case only five photolithographs are required to fabricate microcircuits on P-type silicon substrates without an epitaxial layer. Microcircuits made using this technology can operate at frequencies of 30-500 megahertz. This technology makes it possible to obtain a high percentage of usable highly integrated bipolar circuits that contain 20,000-40,000 components per chip. The active components fabricated by bipolar technology have a boundary frequency of about five gigahertz. Therefore, to support a speed of more than 100 megahertz for the DAC and ADC circuits it is necessary to use a more advanced technological base, for example gallium arsenide.

Table 1 below gives the parameters of certain types of domestically produced microelectronic circuits of assemblies for DAC's and ADC's and also of DAC and ADC integrated circuits. Table 2 below shows the parameters of advanced types of DAC and ADC integrated circuits.

Table 1. Parameters of Certain Types of High-Speed Bipolar DAC and ADC Integrated Circuits.

No.	Name of Parameter	Series 597SA1	597SA2	597SA3
1.	Propagation delay time, ns	6.5	12	300
2.	Bias voltage, mv	-2 - +2	-2 - +2	-5 - +5
3.	Range of synphasal input voltages, v	-3.3 - +3.3	-2.7 - + 2.7	-12 - +12
4.	Output levels	ESL [expansion unknown]	TTL	TTL, CMOS
5.	Power consumption, mwt	300	400	600

[Table continued next page]

[Table 1 continued]

II. Digital-Analog Convertors

No.	Name of Parameter	Series 594KT1	Series 594PA1
1.	Bit of configuration (resolution)	For construction of 4-, 8-, and 10-bit DAC's	12
2.	(Standard) set-up time, ns	200.0	3,500
3.	Nonlinearity, %	±0.05	0.012
4.	Input levels	TTL	TTL, CMOS
5.	Power consumption, mwt	300	650
6.	Output signal of full scale, ma	1; 0.5; 0.25; 0.0125	2.0(±1.0)

III. Analog-Digital Convertor

No.	Name of Parameter	Series
1.	Resolution (bit configuration)	6
2.	Range of input voltages, v	0...-2.0
3.	Nonlinearity, YeMR[expansion unknown]	0.8
4.	Quantization frequency, Mhz	30.0
5.	Signal conversion time, ns	7.0
6.	Output levels	TTL
7.	Power consumption, mvt	900.0

Table 2. Parameters of Advanced Types of DAC's and ADC's

Type of Micro-circuit	Name	Word Length	Speed	Power Con-sumption	Pre-cison
DAC	Code-current DAC controlled from ESL	8	10 ns	500 mwt	0.2%
	Code-current DAC with input control register from ESL and TTL	10	30 ns	500 mwt	±0.05%
ADC	Voltage-code ADC with output register on TTL (input signal 0...-28)	8	30 mhz	2,500 mwt	1/2YeMR
	Voltage-code ADC with output on ESL (input signal-2.5...+2.5v)	6	100 mhz	500 mwt	1/2YeMR

The principal problems that arise during the fabrication of integrated DAC and ADC circuits are the following:

1. Fabrication of defect-free precision photo templates for obtaining convertor structures on a 7 × 7 millimeter chip with around 20,000 components. The size of the minimum element on the photo template here is 1.5 microns with a tolerance of ±0.1 microns, and the number of defective modules does not exceed five percent. It is essential to incorporate the latest optical-mechanical equipment to fabricate such templates.

2. Monitoring technical parameters in the process of fabricating convertor structures on a card during the operations of alloying and photolithography for the purpose of insuring the assigned electrical parameters in the components.

3. Measurement of the parameters of high-speed DAC's and ADC's on a plate and during final monitoring. The difficulties of measuring parameters arise from the requirements for high precision and great speed, as well as the very high values of the parameters. For example, measuring set-up time for the output current of a DAC at 50 milliamps with a precision of 0.05 percent and a speed of 10-20 nanoseconds requires highly precise coordination of the parameters of the devices in the measurement channel, oscillographs with sensitivity of 0.5-1.0 millivolts per centimeter and a range up to 500 megahertz, and appropriate operating amplifiers, comparators, and limiters.

Aperture time of parallel ADC's in the 10-30 nanosecond range and aperture tremor up to 10 nanoseconds should be measured with a precision of ±10 percent, which makes the absolute error of measurement fractions of a nanosecond or picosecond.

The measurement of differential phase, the differential amplification factor, and parameters that describe the signal-noise ratio (noise, power output, and ratio of the mean quadratic value of the signal to the mean quadratic value of noise) is very complex.

At the present time, therefore, we must step up the development of monitoring and measurement equipment for monitoring the parameters of high-speed DAC's and ADC's. This equipment should be able to work under shop conditions. We must also develop standard measurement methodologies.

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DIGITAL ERROR CORRECTION IN MICROELECTRONIC ANALOG-DIGITAL CONVERTORS

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[Article by T. I. Goncharuk, L. V. Teslenko and V. A. Romanov from book "Data Transmission Equipment" edited by Doctor of Technical Sciences A. I. Kondalev, Ordena Lenina Institut kibernetiki, 600 copies, 89 pages]

[Excerpts] One way to improve the precision and metrological reliability of microelectronic analog-digital convertors [ADC's] is automatic correction of the transfer characteristic of the convertor. Until recently realization of the known methods of correction was accomplished in the ADC by hardware means, that is, special devices that perform all the necessary operations to correct ADC errors were included in the structure of the convertor. The development of microelectronic engineering and the appearance of reliable, inexpensive microprocessors and microcomputers now makes it possible to solve the problem of error correction in ADC's by program means.

The present article uses concrete examples to consider correction by microprocessor of errors in the bias, conductance, and nonlinearity of microelectronic ADC's designed to process instantaneous signal values. Without stopping to analyze already known methods of correction (the auxiliary measurements method, the inverse conversion method, and the sample signal method) [1-6], we will only point out that in our case we have selected the sample signal method as the correction method [3] because it is simpler and more efficient than the auxiliary measurements method and, unlike the iterative method of inverse conversions [6], it does not require an increase in conversion time (which is undesirable in an ADC for processing instantaneous signal values). The essential feature of the sample signal method is that a source of sample signals is switched onto the input of the ADC through a multichannel commutator in the intervals between conversions of the signals under study. The microprocessor at the output of the ADC, relying on the results of coding of sample signals, determines the deviation of the transfer characteristics of the convertor from the required figure and puts the correction in the digital code of the signal under study.

To preclude bias error it is sufficient to perform a computation by the formula

$$N_K = N_x - N_o, \quad (1)$$

where N_x and N_K are the code of the number before and after correction respectively, and N_0 is the code of the sample signal, equal in the given case to zero.

The digital correction of conductance is done by computations according to formula (1)

$$N_K = \left[1 - \frac{\Delta N_{o\delta p}}{N_{o\delta p}}\left(1 - \frac{\Delta N_{o\delta p}}{N'_{o\delta p}}(1 - \ldots)\right)\right] N_x, \qquad (2)$$

where $\Delta N_{o\delta p} = N'_{o\delta p} - N_{o\delta p}$; $N_{o\delta p}$ and $N'_{o\delta p}$ are the ideal and real values of the code of the sample signal respectively.

To insure a precision of 0.1 percent it is sufficient to take two members of series (2) [8]

$$N_K = \left[1 - \frac{\Delta N_{o\delta p}}{N_{o\delta p}} + \left(\frac{\Delta N_{o\delta p}}{N_{o\delta p}}\right)^2\right] N_x = K \cdot N_x. \qquad (3)$$

Computation of the coefficient K is done by the microprocessor (series K580 integrated circuits) for 500 microseconds at a cycle frequency of two megahertz and with an eight-bit output ADC code (the code N_K is determined in 300 microseconds). Thus, the total time to correct an ADC conductance error, including time to convert the sample signal, exceeds 800 microseconds. We should observe that conversion of the sample signal and computation of the coefficient K for correcting the conductance error of a microelectronic ADC should not be done more often than calibration of contemporary digital voltmeters. For this reason, the correction time for this error can be evaluated only by the time of performance of the operation of multiplying the coefficient K by the code N_X, which is 300 microseconds.

Conclusions. Digital correction of error makes it possible to improve the precision and metrological reliability of microelectronic ADC's, and to avoid the need to calibrate them, which is made difficult by the limited number or complete lack of built-in elements in such ADC's. The usefulness of digital correction is especially apparent in analog processors of the Intel 2920 type [9], which instead of ADC's and DAC's contain a microprocessor set and are built in the form of one microcircuit.

2. Because of the low speed of contemporary microprocessors, digital correction in highly productive ADC's is still not efficient. The use of digital correction in such ADC's is advisable when the cycle frequency of the microprocessor is 100 megahertz and higher.

3. Debugging the correction programs and calculating their execution time for the series K580 microprocessor set was done by means of a cross-system (developed at the Kiev Polytechnic Institute) which makes it possible to model the work of microcomputers on the basis of YeS [Unified System] computers.

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USE OF ODA-20M UNIT FOR AUTOMATIC DATA TRANSMISSION

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[Article by S. N. Zharovskiy from book "Data Convertors and Data Transmission Equipment" edited by Doctor of Technical Sciences A. I. Kondalev, Ordena Lenina Institut kibernetiki, 600 copies, 89 pages]

[Text] The ODA-20M system was developed for data transmission on multistation communications channels (MCC's). Radio or wire channels may be used as MCC's when subscribers are connected to a multistation system. It is common knowledge that MCC's are most economical for data transmission, even though their use involves a number of difficulties in organizing priority control. The use of programmable supervisors based on microprocessors makes this problem much easier.

Work on MCC's is based on the fact that all station data transmission devices are connected to the common channel in the same way, can carry out various procedures to process data and prepare it for transmission independently, and are always in a duty reception mode. This is accomplished by the fact that the receiving block of the modem in its initial state is connected to the communications channel and its priority for exchanging data on the internal pipeline is set as highest. As soon as any station begins transmitting data, all other stations establish synchronization with the transmitting station and check the affiliation of the data. The addressee station receives the data, checks it, and sends a response-receipt; the other stations continue execution of interrupted jobs until the next transmission.

The switching of a station in the data transmission regime is done when the channel is not occupied (channel state analyzer — CSA) under the control of the priority system, whose jobs include eliminating conflict situations (the competition regime) and insuring assigned service parameters for all stations. In physical terms, priority control is realized by setting various delay quantities upon whose expiration stations are given the right to transmit on the channel the next time it is free.

The ODA-20M system has adopted the following package format. First the characters SBIT are transmitted to tune the receiving units to the selected transmission speed. Then follow the characters SYN, the title (exchange protocol), and the message itself. The last thing transmitted is error check bits. After the last character has been transmitted the transmitting station switches off the channel. On the receiving end the loss of a carrying signal is taken as a sign that the transmission is completed.

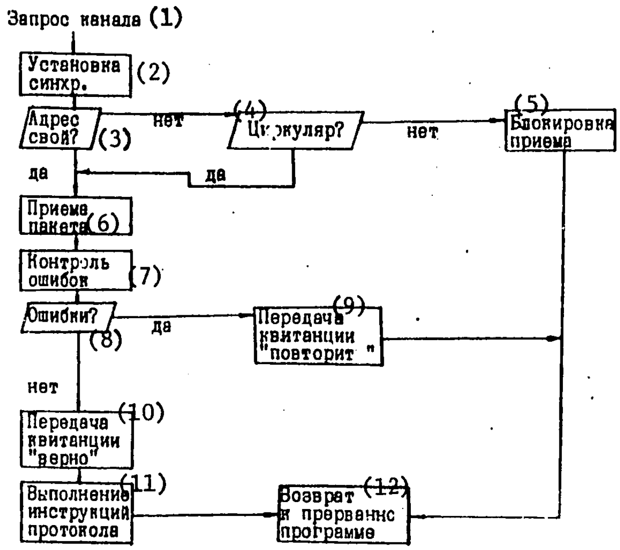
The title occupies a fixed number of bytes (16) and is used as an escort receipt to the package of data being transmitted and also as a responding receipt issued by the receiving station when it receives and checks the data received.

The title contains information on the addresses of the receiving and transmitting points, the sources and receivers of data, information on transmission conditions, the nature of the data, the technique for protection against errors, the priority system, and so on. When a response receipt is transmitted the service characters SBIT and SYN are also transmitted first. Then the receipt is transmitted, with contents similar to the title of the package. Information on the quality of reception (failure, errors, or without errors) is given in a special byte (the eighth) in this case. Unlike the title of the package, in the response receipt the package length, given in bytes 7 and 6 is equal to zero.

Let us look at the work of the system in sequence in the receiving and transmitting modes. There are two types of modems that can be connected to the internal pipeline: the high-speed channel (HSC) modem and the low-frequency channel (LFC) modem. The HSC modem works with the microprocessor as an ordinary computing unit, using standard internal pipeline signals and parallel eight-bit representation of data for this purpose. The functions of establishing synchronization, decoding the address, and shaping the characters are performed by hardware in the modem itself. The LFC modem performs only the functions of shaping the channel signal under control of the microprocessor, switching the channel from the reception mode to the transmission mode, and identifying moments of passage by the zero level according to the signal being received. All the other functions are performed by microcomputer software. For this reason LSC modems can only be used for physical modeling of signal modulation and demodulation during data transmission. It is advisable to use it when the ODA-20M apparatus is connected to data transmission systems which use series-produced data transmission equipment. For example, when data is transmitted by biopulse signal (or one-time relative phase modulation) 100-150 microseconds of working time of a 580IK80 type microprocessor is used for one bit of information, which limits the rate of transmission to 7-10 kilobits per second.

Figure 1 below shows a block diagram of the algorithm for data processing in the receiving mode for an HSC modem. The modem tunes itself to bit synchronization with the channel signal according to the SBIT characters. Then the characters by which cyclical synchronization is established are received. The first character, which differs from SYN, is received as the address of the reception station or the sign of a circular message. If the batch of data (or responding notice) is addressed to a particular station, the work of the microprocessor is interrupted and the batch is received in internal memory. The characters are counted and check sequences are formed in parallel. Then the error check subroutine is connected in. The check sequences that are transmitted are compared

Figure 1



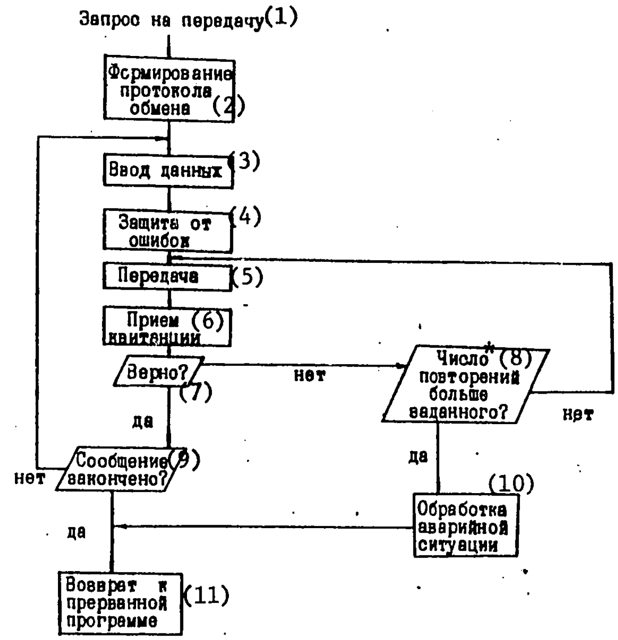
Key: (1) Channel Query;
(2) Establishing Synchronization;
(3) Your Address?;
(4) Circular?;
(5) Suppression of Reception;
(6) Reception of Batch;
(7) Error Check;
(8) Errors?;
(9) Transmit "Repeat" Notice;
(10) Transmit "Correct" Notice;
(11) Execute Protocol Instructions;
(12) Return to Interrupted Program;
(да) Yes;
(нет) No.

---

with those received on the spot. Then a responding notice is formed and sent to the transmission station. If no errors are found, the receiving station begins executing instructions contained in the title of the package. If there are errors a universal switch transfers control to the background program interrupted earlier. The transmission station receives a responding notice and uses it to decide on the need for repeating the transmission and the conditions of doing so (number of repetitions, change in speed, breaking down the message, and the like).

Figure 2 below illustrates preparation for data transmission and transmission. The title of the batch is fed to the computer by directive or is read from the

Figure 2



Key:
(1) Transmission Request;
(2) Shaping Exchange Protocol;
(3) Data Input;
(4) Error Protection;
(5) Transmission;
(6) Receipt of Notice;
(7) Correct?;
(8) Number of Repetitions More than Assigned?;
(9) Message Completed?;
(10) Processing of Emergency Situations;
(11) Return to Interrupted Program:
(да) Yes;
(нет) No.

---

library of standard titles stored in read-only memory. Then the batch shaping subroutine is used to feed data to internal memory and the check sequences are formed. After this control is transferred to the transmission generator. This subroutine is executed on the conditions that (1) the channel is free, (2) there is authorization for priority control, and (3) a responding notice to the batch of data transmitted earlier has been received.

The transmission generator controls output of the batch to the modulator and switches the channel to transmit. After transmission is completed the processor interrupt is removed and it returns to the background program. Other requests for transmission at the particular station are held up until notice is received confirming reception. This restriction is necessary because a new request for transmission may spoil information in the "old" batch which must be transmitted again in case of incorrect reception.

Priority control over access to the communications channel is necessary to avoid conflicts between stations performing data transmission procedures.

Because this system does not provide for querying the states of the stations or centralized control of access to the channel, control functions are performed autonomously at each station. Different control disciplines can be established in this case, for example station priorities that are fixed or vary according to a certain law, in dependence on overall channel traffic, permissible waiting time, length of the queue of batches, and so on. The exchange protocol indicates the particular nature of channel control discipline. In data exchange systems where control adaptation is required, none of the stations is given arbiter functions. This station records all batches transmitted on the channel, determines the load of the stations, and periodically transmits circular batches that contain new instructions on priority control.

Physical realization of different priority levels is accomplished by a priority control block which issues authorization for transmission to the particular station within a certain time after the communications channel becomes free. This delay is proportional to the priority level. Thus, a station which has a higher level of priority receives authorization to transmit and occupy the channel.

In conclusion it should be noted that the advantages of the programmable ODA-20M equipment are seen most vividly where there must be adaptive control of priority access, rate of transmission, and various other hardware functions depending on the current state of the system.

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HARDWARE OF ODA-20M DATA EXCHANGE SYSTEM

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[Article by P. A. Abysov, S. N. Zharovskiy and A. Z. Divinskiy from book "Data Convertors and Data Transmission Equipment," edited by Doctor of Technical Sciences A. I. Kondalev, Ordena Lenina Institut kibernetiki, 600 copies, 89 pages]

[Text] The development of data transmission hardware is determined in large part by the fast-growing needs of all areas of human activity for integrated, distributed data processing systems. In recent times data transmission networks for both general use and special purposes have become widespread. They are constructed on different principles using wire, ground, and satellite radio channels. As these systems become more complex, the requirements for data transmission equipment grow and broaden substantially. The significant differences in scope of data transmission systems (local and global), in types of communications channels and terminal equipment used, and in other aspects have led recently to the development and production of a broad assortment of data transmission equipment, but it is still not always adequate because of the rapid modernization of components of data processing systems and the different types of problems.

For this reason the attention of data transmission equipment developers is turning to programmable data transmission hardware which is easily adapted to the application conditions and is therefore more universal and economical.

A definite advance in this area was seen with the appearance of microprocessor LSIC's, which made it possible not only to increase the universality and flexibility of data transmission equipment, but also to make it much cheaper than equipment based on hardware logic. At the same time, the use of microprocessors permitted a significant improvement in the intellect of data transmission equipment, assigning to it many functions traditionally performed by channel supervisors, concentrators, and linked computers; in numerous cases they were also given the functions of the computers at subscriber points and terminal complexes.

Therefore, this area of work is pursuing the objective of building integrated hardware for distributed data processing in which the functions of data collection, processing, and transmission are interrelated and realized by means of uniform hardware.

One of the most widespread methods in data transmission engineering is using a microprocessor as the communications channel supervisor. In this case the microprocessor is given the following functions: compacting data; control of input-output; storage and shaping of data; conversion of codes; organization of exchange protocols and their processing; detection and correction of errors; control of priority discipline for channel use; communication with numerous subscribers; synchronization, and others.

Many types of data transmission equipment have already been built with analogous schematic diagrams. For example, the batch communications system based on the IMP-16 microprocessor (England), the Modbus system from the Gould Incorporated company which works with a 1 8085 microprocessor (United States), developments from the Allen Bradley Company, Texas Instruments, and others.

The ODA-20M is one of the first domestically produced developments based on program-controlled data transmission. Use of a microprocessor control system opens broad opportunities for matching the technical specifications of the data transmission equipment with the concrete requirements that arise when setting up systems to automate scientific experiments.

The proposed control system has a pipeline structure. Interaction among functional blocks of the system, that is, among the central processor, memory unit, control and indicator console, modem, and input-output units is carried on through a "Common Line" interface.

The central processor is based on a K580IK80 microprocessor using series K155 microcircuits.

The memory unit is a semiconductor internal memory with random access and a semiconductor read-only memory. The memory unit uses K565 RU1 and K565RYe4 microcircuits. Minimum capacity is 3-4 kilobytes. Modular enlargement of the memory unit is possible.

The universal control console enables the operator to control the processes of data receiving, transmitting, and processing. The characteristics of the proposed system (the characteristics of the linked computer and data transmission equipment) are taken into account in the control console. It has means for debugging the control system. The control and indicator elements enable the operator to carry on operational monitoring during the work of the system based on such features as the address of the subscriber, the number of the exchange protocol, the level of priority access to the common communications channel, the state of the subscriber stations, the state of the communications channel, and others. The operator accomplishes all this by pressing function keys. In the same way the operator is able, when necessary, to modify these exchange features. At the same time, the control and indication elements support work with the processor part of the equipment as a conventional microcomputer. For this purpose there is also the possibility of connecting input-output units such as a photoreader, punched card unit, electric typewriter, magnetic card, and so on, to the ODA-20M equipment.

The program structure adopted in this system for the processes of controlling transmission and receiving and data processing insures maximum system flexibility and makes it possible to use the ODA-20M equipment as data transmission equipment, as a linked processor, and as a station microcomputer with the possibility of significantly enlarging memory capacity and the overall productivity of the system.

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EXHIBITIONS AND COURSES

HUNGARIAN COMPUTERS AT BUDAPEST FAIR

Moscow PRIBORY I SISTEMY UPRAVLENIYA in Russian No 3, Mar 82 pp 46-47

[Article by D. Chani and M. Tot, Hungary]

[Text] An international fair exhibiting computer equipment is held in May of every year in Budapest. Hungarian and other foreign companies have shown their most recent resources and systems in the central pavilion of the exhibition. This year the systems that were shown were based mainly on microprocessors. This article primarily examines new equipment from Hungarian plants and institutes.

Videoton Products

Videoton exhibited several systems at the fair. Included among them are a data collection system based on the YeS-1010M computer, designed cooperatively by specialists of Videoton and IGV enterprises and intended for use in department stores. The central computer can be connected to 8-16 cash register terminals equipped with a photoelectric reader. These terminals can be located up to 1.5 km away from the computer (without a modem).

Possible applications of the YeS-1011 system were demonstrated. The AVIT system is a modular system for motor vehicle service enterprises. Despite the fact that its main function is to support the servicing of motor vehicles, the system can also be used by various service-rendering enterprises. Data are prepared by a DMC data base maintenance system. Information is entered into the system from terminals separated from each other and from the central computer. Another application of the YeS-1011 system is an image processing system developed jointly by Videoton and the Institute for Coordination of Computer Technology. This system can be used to carry digital information from a screen to any accumulators, to make statistical calculations, to display pictures, to magnify or reduce images and to compose and edit text.

A group transmission unit that can be connected to a modular YeS-1011 system was offered for remote information processing. It transmits information reliably at moderate speed.

The RPT/80F general-purpose terminal control unit (see figure [figure not reproduced]) was shown for the first time. It is used in banking and bookkeeping applications. Another new item was a unit that reads symbols off of punchcards; it is used to read digits and text typed on a punchcard.

Exhibits of the Telefongyar Plant

This plant produces remote data processing units (modems, user stations, a remote processor) that are well known to the YeS and SM computer systems. The plant's new article--a YeS-8534 (TAP-34) intelligent terminal--won the fair prize. It operates at a transmission rate of 2,400 baud, it is made out of highly integrated components, and it is controlled by a microprocessor. A terminal can transmit data to a computer or a remote terminal in batch processing mode or in a dialogue system. Various peripheral units can be connected to it: an alphanumerical keyboard, a punchcard reader, a flexible magnetic disc accumulator, a DZM-180 or "Consul-2111" printer and a double flexible magnetic disc accumulator with a total capacity of 500,000 bytes.

Products of the EMG Plant

An EMG777 computer was exhibited for the first time this year at the fair. It is intended for scientific and technical calculations and for use in measuring systems and data processing systems. It is capable of graphical expansion to permit solution of two-dimensional graphical problems. The principal characteristics of the computer are: Automatic plotting, graphical data output in dialogue mode at high speed, provision of data bank services in dialogue mode at a high intelligence level. The unit contains an AM-2901 basic microprogram processor and three Intel 8085 peripheral processors. The built-in peripheral units include an alphanumerical graphical screen with a diagonal measurement of 31 cm and two places (interfaces) for connection of a typewriter and an alphanumerical graphical printing unit. Expanded BEYSIKis the programming language.

IGV Exhibits

BDT-100 cash register terminals were exhibited. These are connected to a YeS-1010M to form a trading enterprise data collection system. The cash register terminals can be connected to the computer through a transmission line or a data concentrator. The terminals are supplied with EAN and UPS bar code readers.

A VG-200 duplicator intended to make copies of A4 format documents is also a new development of this plant. It operates at a speed of 12 copies per minute.

Orion Products

One of the Orion plant's new developments is a YeS-8007 fully duplexed modem; after receiving the Gold Medal at the Leipzig Fair in 1981, it earned first prize at the Budapest Fair. This modem quadruples the rate of transmission of existing duplex modems without changing the transmission method. Owing to this, communication in two-conducter switching circuits may be increased simply by substituting the modems. Up until now, a rate of 1,200 baud could be achieved only with four-conducter direct links using an FSK modem. The same transmission rate can be achieved with two-conductor transmission lines using the new modem built by the Orion plant (AM-12 TD is the plant code) at lower cost. The YeS-8006 modem is capable of only semiduplex transmission. Owing to change in transmission directions, a delay of 300 msec is created within the block. When a fully duplexed AM-12 TD modem is used, this delay is eliminated.

Mention should also be made of a data preparation system called "Ordash" by the Orion plant. It can be used to collect and monitor data of any form. The system consists of a microcomputer and eight workplaces. Data from these workplaces are transcribed onto a disc. These places are supplied with a keyboard-equipped display.

Exhibits of the Institute for Coordination of Computer Technology

The institute is focusing its efforts on the use of computer technology in the national economy. Systems characteristically used in the institute's research work, to include for agriculture, food industry, power engineering, warehouse management and transportation, were shown at this fair. Among the exhibits the "Teleterm," a simple, inexpensive terminal, aroused considerable interest. It possesses a built-in pushbutton telephone set. It works as a computer terminal, and it provides a direct communication link, by a telephone line, between an information system and production personnel. Microprocessor control means that the equipment can be adapted to particular tasks. Use of the new unit to control a meatpacking plant warehouse was demonstrated.

Mention should be made of software created for a color display. This software could be used in the processing of images in autonomous mode, or to achieve a link-up with a computer. It can process various sorts of images: medical, meteorological, materials testing images and so on. In order that it could be used with large systems, the institute has created a possibility for adapting it to TPA 11/40 and YeS-1011 computers.

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CSO: 1863/133

COMPUTER SCIENCE COURSES ANNOUNCED

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 6, Nov-Dec 81 p 100

[Announcement of computer science courses conducted in Budapest at the International Center for Instruction in Computer Science for 1982]

[Text] International Courses in Computer Science in Budapest

International Center for Instruction in Computer Science (SZAMOK)
Postal address: 1502 Budapest 112, P. O. Box 146, Hungary

International Courses for 1982

International Courses for Retraining of Personnel in Computer Science at SZAMOK in 1982

	Course Title	Course Date/Language [all given in English unless otherwise noted]
1.	Concurrent Programming	1-5 March
2.	Modern Methods of Design in Data Processing	8-12 March
3.	Efficient Structured Programming in COBOL	15-19 March
4.	Reliability of Computer Systems	22-26 March
5.	Practice in Design of Data Banks	29 March - 2 April
6.	Management Systems	5-9 April
7.	Structured Design of Programs by the (Varniet) Method (Practice)	19-30 April
8.	Use of Digital Simulation	19-23 April
9.	Project Management	26-30 April
10.	Structured Design of Programs by the (Jackson) Method (Practice)	3-14 May
11.	Structured Design of Systems	3-5 May
12.	Practice in Structured Design of Systems	6-8 May
13.	Management of Working Groups of Programmers	10-14 May
14.	Efficient Problem-Solving by Using PROLOG	17-21 May

15.	Designing Reliable Use of Computer Hardware	17-21 May
16.	Testing Computer Systems	24-28 May
17.	Using Graphic Displays in Engineering Design	31 May - 4 June
18.	Application Technology for the R-11 Megaminicomputer	Russian Language, 7-11 June
19.	Automation of Library Operations and Information Services	6 Sept. - 1 Oct.
20.	Applied Statistics in an Enterprise by Using Computers	Russian Language, 4-8 October
21.	Evaluation of Working Systems for Production Control and Inventory Management	11-15 October
22.	Software Portability	Russian Language, 18-22 October
23.	ADA Programming Language	25-29 October
24.	VIDEOTON NETWORK SYSTEM	1-5 November
25.	Using the Network Planning Method	8-12 November
26.	Computer System Efficiency Analysis	Russian Language, 15-19 November

In addition to course students, our hotel accepts foreign tourists as well throughout the year.
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8545
CSO: 1863/82

PUBLICATIONS

ABSTRACTS OF ARTICLES IN JOURNAL 'AUTOMATION AND COMPUTER TECHNOLOGY', NOVEMBER-DECEMBER 1981

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 6, Nov-Dec 81 pp 95, 97, 99

UDC 681.324

OPTIMIZATION OF BATCH PROCESSING BY THE METHOD OF DECISION FAMILIES

[Abstract of article by V. I. Khoreyev]

[Text] A design method is discussed for determining all optimal schedules for batch data processing in associations reducible in structure to open. The result is oriented to controlling processes in shared-use computer centers. Bibl. 5.

UDC 681.3.06:681.323

EVALUATION OF TWO TASK SCHEDULING ALGORITHMS FOR HOMOGENEOUS COMPUTER SYSTEMS

[Abstract of article by V. Yu. Bakenrot, V. V. Kolobayev and O. B. Makarevich]

[Text] Authors evaluate operation of two algorithms for minimax planning of solution to a package of simple independent problems in homogeneous computer systems, based on descending ordering of the problems by their solution time and assignment of them to machines in that order with regard to machine busy time (the well known LPT algorithm and its modification), for which there is defined the range of values of the upper bound of the absolute error of the corresponding schedules when the specified condition for problem solving time is met. Bibl. 2.

UDC 681.32:519.713

OUTPUT DECOMPOSITION FOR COMBINATIONAL PROGRAMMABLE LOGIC ARRAY STRUCTURES

[Abstract of article by M. I. Shvartsman]

[Text] Discussed is the problem of implementing a system of Boolean functions with programmable logic arrays (PLA) for the case when the number of system functions exceeds the number of PLA outputs. Selected as the criterion of decomposition is the minimum of the sum of conjunctions of all subsystems up to minimization. Suggested is the basic algorithm for obtaining decomposition, as well as two modifications of it. Test results and statistical evaluations are given. Tables 1, bibliography of 7 titles.

UDC 681.325

DESIGN OF HIGH-SPEED SPECIALIZED COMPUTERS TO REALIZE MULTIPLACE EXPRESSIONS

[Abstract of article by V. I. Zhabin, V. I. Korneychuk and V. P. Tarasenko]

[Text] A method is suggested for synthesizing the structure of high-speed specialized computers with tight coupling between operation devices of the quasi-parallel type, which permit overlapping the processes of bit-by-bit input and output of information beginning with the high-order bits. Figs. 2, bibl. 4 titles.

UDC 519.713

RACE-FREE CODING OF ASYNCHRONOUS AUTOMATA WITH ELEMENTS OF STORAGE WITH DIFFERENT STABILITY

[Abstract of article by A. N. Melikhov, L. S. Bershteyn and M. M. Chernyak]

[Text] An algorithm is suggested for race-free coding of asynchronous automata, oriented to use of flipflops with a different number of stable states. In the process, the problem is solved for optimizing the result of coding from the position of minimizing the summary stability of the multistable storage elements used. Tables 6, figs. 1, bibliography of 4 titles.

UDC 519.711.7:681.324

GLOBAL OPTIMUM STRUCTURAL SYNTHESIS FOR DATA TRANSMISSION NETWORK USING COORDINATION THEORY

[Abstract of article by D. I. Mladenov and T. A. Stoilov]

[Text] The problem of global optimum structural synthesis is formulated and solved. It considers delay times in networks, reliability and cost and defines the network structure and communication channel throughput. The problem is formed by composition of two partial problems, each of which determines certain parameters and characteristics of those mentioned above. The synthesis process is a procedure which is affected a certain way by the solutions to the partial synthesis problems. As a result of this, the solution to the problem of global optimum structural synthesis is derived. The effect of the partial synthesis problems is considered by using coordination theory algorithms. An example of global synthesis of network topology and channel throughput by the criterion of cost is given. Figs. 3, bibl. 7.

UDC 519.58

SEARCH FOR OPTIMAL SOLUTION OF COMBINATORIAL PROBLEMS WITH BOOLEAN VARIABLES ON REARRANGEABLE CELLULAR COMPUTING ARRAYS

[Abstract of article by V. O. Groppen]

[Text] This work covers the problem of efficient allocation of resources of cellular computing arrays when solving extremal combinatorial problems with Boolean variables by exhaustive search procedures. Problems of synthesis of various resource allocation strategies and implementation of them in specific situations are discussed. Results are given for efficiency test of various strategies by using program simulators. Implementation of a number of approaches is illustrated by examples. Figs. 5, bibliography of 8 titles.

UDC 519.7

STRUCTURAL AND LOGICAL METHOD OF APPROXIMATE COMBINATORIAL OPTIMIZATION IN PROBLEMS OF ALLOCATING COMPUTER CAPACITY

[Abstract of article by V. I. Levin]

[Text] The problem of optimum distribution of problems between n computers is considered. The efficiency of solving the i-th problem on the j-th computer is a_{ij}. Considered the criterion of the optimum is the maximum of the summary efficiency from the solution of all problems. A general method is presented for the approximate search for the extremum of the function of discrete variables, based on using infinite-valued logic, with the basic operations $x \vee y = \max(x,y)$--disjunction, and $x \wedge y = \min(x,y)$--conjunction. For the matrix $A=||a_{ij}||$ of efficiencies, a logic determinant-characteristic is introduced, the computation of which yields the solution to the problem. An approximate method for computing this characteristic, possessing complexity exponential by n, is presented. Tables 2, bibl. 7.

UDC 519.216

ONE PROBLEM OF OPTIMIZATION WITH BOOLEAN VARIABLES

[Abstract of article by A. N. Antamoshkin]

[Text] Discussed is the possibility of using an algorithm for random search with adaptation and a modification of it, intended for conditional optimization of functionals with Boolean variables, for solving the problem of unconditional optimization. The proposed transform of the problem permits using the algorithms essentially in unchanged form. Bibliography of 4 titles.

UDC 681.3.068

PRINCIPLES OF COMPOSING CONSTRUCTOR PROGRAM FOR GENERATING A SYNTAX PARSER BY METHOD OF G(k)-GRAMMARS

[Abstract of article by V. S. Zonis and A. S. Shumey]

[Text] Discussed are the principles for designing the constructor program for automatic generation of a syntax parser by using the method of G(k)-grammars, which is an evolution of the method of LR(k)-grammars. The program consists of two parts: 1) a subroutine for analysis of the source grammar and representation of it in main storage in the form of two tables: a table of nonterminal symbols and a table of grammar rules, and 2) a subroutine proper for generation of a table of the set of parser states. The entire constructor program has 1200 instructions in SM-3/SM-4 Assembler. Tables 1, bibliography of 4 titles.

UDC 681.3.014:621.391.19

PROCESSING OF RASTER IMAGES OF EXTENDED OBJECTS

[Abstract of article by A. G. Vostretsov, V. I. Kushnir and A. N. Yakovlev]

[Text] Automatic processing of a raster image in real time is discussed. The processing algorithm includes the stage of selecting separate images and the stage of detecting among them figures close to a parallelogram. A structural scheme of a device that implements this algorithm based on a microcomputer is given. Figs. 3, bibliography of 4 titles.

UDC 681.142.4

ESTIMATES OF DYNAMIC CHARACTERISTICS OF MULTIMACHINE SYSTEMS FOR AUTOMATING EXPERIMENTAL RESEARCH

[Abstract of article by Yu. F. Ryabov and V. P. Khomutnikov]

[Text] Simulation modeling is used to study the different alternatives for designing multimachine systems for automation of experiments. Examples of relations between user indicators of efficiency and the load and structural and quantitative parameters of the system are dervied. Tables 2, figs. 5, bibl. 9.

UDC 551.46:681.3:53.08

INTEGRATED SYSTEMS FOR AUTOMATION OF SCIENTIFIC RESEARCH ON MULTIPURPOSE RESEARCH VESSELS

[Abstract of article by O. S. Zudin, S. N. Domaratskiy, I. P. Kotik, G. N. Kuklin, A. A. Novikov, L. S. Sitnikov, O. Laaksonen and R. Aarinen]

[Text] Problems of organization of the structure of scientific research automation systems (SANI) for multipurpose ships are discussed using as an example the Integrated System for Automation of Scientific Research on the "Akademik Mstislav Keldysh," a multipurpose research ship for the USSR Academy of Sciences. This system combines into a single entity the facilities for automating oceanologic experiments, automatic ship navigation equipment, facilities for acquisition of meteosynoptic data and computer facilities in the form of 12 different computers and 3 crates with modules of CAMAC apparatus. It is shown that maximal flexibility for such systems is afforded by using a hierarchical structure with data processing and logging distributed by levels of the hierarchy and the bus-modular method of organizing the hardware at all levels. Problems of computer interaction, organization of links between the different subsystems and the selection of interfaces for the different levels are discussed. Special attention is paid to joint use of the CAMAC system and the IEC instrument bus. Incorporating three resources for the data logging subsystem is suggested: a parameter description table, a status table and a directory. Problems of self-identification of data are broached. Special attention is paid to time tags. Figs. 4, bibliography of 6 titles.

UDC 519.872.2

DESIGN OF NONHOMOGENEOUS COMPUTER SYSTEMS

[Abstract of article by Yu. I. Ryzhikov]

[Text] A computer system is considered as a queueing system of the form $M/\vec{M}/\vec{n}$, where the channels of each of k types have their own parameter μ_i for allocation of servicing time. The system states are described by the total number of requests in in and by the number of channels of each type that are doing the servicing. An iteration scheme is suggested for design of the allocation of the number of requests in an open system with an unrestricted queue and a modification of it for a restricted queue and for a closed system. A method for computing servicing time indicators is shown. Characteristics of a PL/1 program that implements the method and a numeric example are given. Tables 1, figs. 2, bibliography of 7 titl.

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