MASK SHOP INFORMATION SYSTEM

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Introduction

The Mask Shop Information System (MSIS) is a computer system which provides real-time control as well as information retrieval functions for a shop where integrated circuit masks are made. This system is now in use at two Bell Laboratories locations, one at Murray Hill, New Jersey, and the other at Allentown, Pennsylvania.

Each mask shop contains its own complex of Bell Laboratories designed, photolithographic devices. The original artwork for each mask level is produced on a Primary Pattern Generator, a device which uses a laser beam to accurately expose a pattern on a photographic plate. Specially designed Reduction and Step-and-Repeat Cameras are used to arrive at the final mask. Developing, inspection, and copying facilities are also part of the shop.

For each job, the mask shop accepts as input a magnetic tape with a file of pattern description data for each level of an integrated circuit mask, and a deck of computer cards describing the job. The resulting output of the shop is a set of glass, chrome, or mylar integrated circuit masks.

While a typical job is being processed, many glass plates are produced as each mask level goes through the following process stages.

1. Primary Pattern Generation – a set of patterns are produced on 8" x 10" glass plates.

2. Reduction – the patterns are reduced, and a corresponding set of 4" x 5" glass plates are generated.

3. Step-and-Repeat – the reduced patterns are arrayed to make a 4" x 5" master mask, and

4. Print – the master is reproduced many times to produce the 4" x 5" or 2" x 2" glass, chrome, or mylar working copies.

Figure 1 shows the various stages involved in the making of one integrated circuit mask.

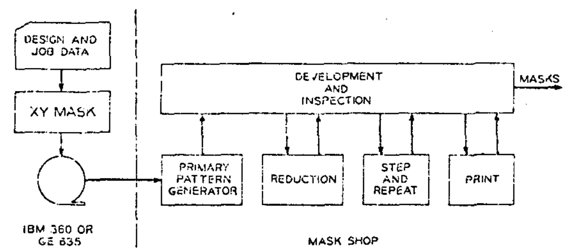

Figure 1. Stages in Making an Integrated Circuit Mask

At each stage, processing information is needed in addition to the physical input. Furthermore, the inspections following each stage of processing may result in the repetition of a processing stage and consequently the production of even more glass plates. And naturally, shop personnel would like to know the location and status of all plates for any particular job at any time. The computer-based system known as MSIS is used to keep order reigning among this multitude of glass plates and associated data.

MSIS Hardware

The basic MSIS hardware consists of a PDP-9 computer with a million-word disc, a magnetic tape drive, and a card reader. Communication with shop operators is accomplished by means of two teletypewriters, a data link to another PDP-9, a data link to a PDP-8, and two custom-made keyboard/display sets.

The links between the various pieces of hardware which make up MSIS are illustrated

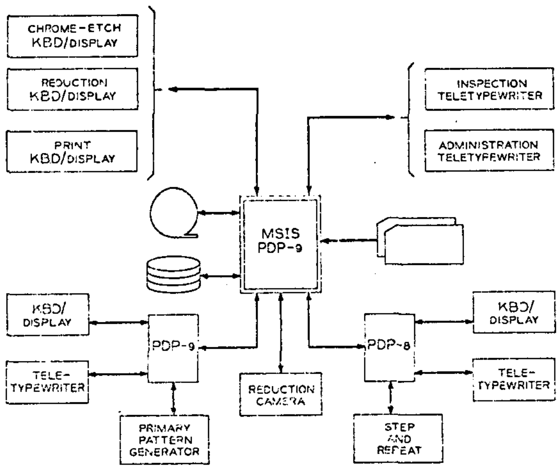

Figure 2. MSIS System Configuration

in Figure 2. At the center is the PDP-9 which continually operates using the programs and data stored on disk. MSIS actions are initiated by an interrupt from one of the following input/output devices:

1. Administration Teletypewriter – used to initiate the entry of a job deck from the card reader, to communicate any needs or problems to the shop administrators, and to provide responses to queries presented by shop personnel.

2. Data Link Between Primary Pattern Generator (PPG) Control Computer and MSIS – used to allow the PPG operator to ask for new work assignments and to transmit performance data during PPG operation.

3. Reduction Keyboard/Display Set and Camera Signals – provide communication with the reduction camera operators and the capability of obtaining data on camera operations.

4. Data Link Between Step-and-Repeat (S&R) Camera Control Computer and MSIS – Allows the S&R Camera operator to ask for new assignments and permits transfer of data while the camera is operating.

5. Print Keyboard/Display Sets – Provides communication between MSIS and the operators of the Contact Print and Etching Stations.

6. Inspection Teletypewriter – Used for communication between MSIS and inspection operators.

MSIS Software

The information system is a set of programs written in PDP-9 assembly language and operating under a specially designed multiprogramming monitor. Eight thousand words of PDP-9 core are subdivided into a common data area and seven fixed-size execution areas; one execution area contains the monitor, three contain in-core tasks, and the last three are used for the swapping of tasks from disk. There are 45 disk tasks presently used in MSIS and the number continues to grow.

The layout of MSIS core storage is illustrated in Figure 3. In general, any signal from the external world is picked up by the monitor and interpreted enough to determine which task should be activated to respond to the signal. A task list, ordered according to priority, is used to initiate task execution and to keep track of the status of tasks. Task execution and I/O transfers are overlapped.

SYSTEM REGISTERS 30
EXECUTION AREA 0 (3300)
EXECUTION AREA I (1200)
EXECUTION AREA II (1100)
EXECUTION AREA III (1000)
EXECUTION AREA IV (25)
EXECUTION AREA V (75)
EXECUTION AREA VI (170)
COMMON (1292)

Figure 3. MSIS Core Layout

In addition to stimuli from the external word, there are a set of tasks which are activated periodically under control of the real-time clock; these periodic tasks keep check on the integrity of the system. That is, if MSIS needs an input in order to continue processing a job and an unreasonable amount of time has passed since this input should have been received, a periodic task will discover this and print a warning message.

The tasks communicate with each other using queues, common data words, and various job description blocks which are stored either in the common core data area or on disk. Only a few major tasks make changes to these shared data blocks, and these tasks are situated in the execution areas and activated in special ways to avoid the possibility of conflicts. Many tasks, however, can read these data blocks and relate the information to the external world.

MSIS Functions

The functions of MSIS can best be explained by describing a typical job that passes through the shop. An engineer has described the patterns of each level of his integrated circuit in a graphical language called XYMASK* and has produced a magnetic tape which contains the pattern descriptions in a form suitable for processing by the shop's computer-controlled Primary Pattern Generator.

In addition to his XYMASK tape, the engineer has prepared a deck of cards in the MSIS language (a typical deck set-up is illustrated in Figure 4). This deck describes:

1. the location of the pattern files on his XYMASK tape,
2. at what magnification he has described his pattern,
3. how he would like the patterns arranged on his final output,
4. to what tolerances and what detail he would like the plate inspected,
5. the size and type of the working copies he desires,
6. where he wants his output delivered, and
7. some special information for management and accounting reports.

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            JOB DESCRIPTION

ENGINEER    MH, 1112, B65420, J.H. GILMØRE X5023

CASE        39500-20

DEVICE      A1502, BEAM LEAD GATE

MASK        B850122-1-4, 2135, ARRAY-L2
        PATTERN   B413622-1-2, ART
        PATTERN   L100600-1-3
        PATTERN   L200501-1-2

MASK
 •
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 •
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END
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Figure 4. MSIS Input Deck

A shop operator places the MSIS deck in the card reader and types in JOB on the main teletypewriter. If the data in the deck is reasonable and consistent, MSIS accepts the job, stores the data on disk, gives the operator a bin location for the XYMASK tape, and puts the patterns requested on the queue for the Primary Pattern Generator.

Eventually, the operator of the Primary Pattern Generator in the next room types in a request that he needs a new assignment. The PDP-9 computer controlling the Primary Pattern Generator then sends a message across the data link to MSIS that an assignment is needed, receives a reply, and tells the operator to mount the XYMASK tape stored in a certain bin. The computer automatically selects the correct file on the tape and controls the generation of the pattern. The pattern plate is then taken to development. Only MSIS need be aware of the existence and requirements of this plate since it has an identifying number exposed on it. The PPG continues getting assignments until an 8" x 10" glass plate has been made for each pattern of the job.

All developed PPG plates for this job eventually arrive in the inspection area. An inspector, communicating with MSIS via

*A language and computer program developed at Bell Telephone Laboratories which accepts pattern descriptions in graphical form and translates the data into the form needed for production of the patterns on any of a variety of output devices.

teletypewriter, uses the plate identification number to ask for detailed inspection information and to accept or reject each plate accordingly. If a plate is rejected, MSIS automatically queues it to be remade. When a plate is accepted, MSIS asks the operator to store the plate in a specified slot of a numbered plate carrier.

When the plate carrier is full or the Reduction facility needs work, MSIS directs an operator to take the carrier into the Reduction camera room. The Reduction operator, using a keyboard/display set to communicate with MSIS, asks for work. The assignment displayed on the scope includes the carrier location of the plate as well as the Reduction camera that should be used. MSIS can automatically read the plate identification when the plate is loaded in the camera and can check that the correct plate has been loaded in the correct camera. After each plate is exposed, it again gets sent to development.

A similar inspection occurs again and the accepted plates are put in a carrier that is soon taken into the Step-and-Repeat camera room. When an operator in the Step-and-Repeat facility asks for work, MSIS is asked to send an assignment across the data link to the PDP-8 computer controlling the camera. Using the array information entered by the engineer, MSIS also continually sends data to the control computer giving the location of each pattern center as the plate is being made. Thus a set of reduced patterns are used to make a master mask for each level of the integrated circuit.

Following development, the master masks are again inspected and then sent to the printing facility. The printing operator receives his assignments on another keyboard/display set. As the working copies of a job are completed, they are placed in a bin assigned to the job. When all working copies are in the bin, MSIS sends a message via the main teletypewriter to give the operator the information necessary to deliver the job.

The basic function of MSIS is to assign tasks so that many jobs can be simultaneously handled by the system in an efficient manner. While controlling all the shop facilities and keeping track of jobs and plates, MSIS is also checking for problem situations, answering spontaneous teletypewriter requests about jobs, and accumulating data on shop operation for reports.

Operating Success

MSIS was put into operation at Murray Hill in mid-1970. The system went through all the trials and tribulations that usually accompany putting an on-line system on the air. Early difficulties seem to have been the result of three basic problems. The first was that the designers of MSIS were not able to anticipate all the input errors that could occur; despite their attempts, it took an actual shop run over a long period of time to discover all the unlikely inputs that could cause catastrophe to MSIS.

Secondly, MSIS depended on too many different external inputs to perform a decent debugging of the system before it was installed in the shop. When the system was presented with a real shop situation, loading problems occurred that had never been anticipated. Perhaps, a complex program simulating worst-case shop conditions would have solved this problem. And third, MSIS could not keep up with the innovations. Shop methods continually evolved as the shop personnel discovered that they could get better output by doing things in ways that had never been envisioned, and MSIS had to keep in step.

By the end of the year, it was realized that the list of problems and requests for improvement were worth the trouble of taking the system off the air and devoting full time to making it truly operational.

Thus the first six weeks of 1971 were spent by fixing all known errors and then continually performing shop operations under worst-case conditions until new problems developed. A goal, known as the "load test," was set. This test consisted of processing 30 jobs, making all conceivable errors in input. When this was accomplished successfully, the system was put on-line again.

Since mid-February, the system has been running at Murray Hill with minimum problems. The installation of the Allentown MSIS lagged behind the Murray Hill system because of physical differences in the shop facilities. In early April, a similar load test was performed at Allentown, and MSIS is now operational at both locations.

During this debugging and improvement phase, two good points in the MSIS design stood out. For one, MSIS is designed in a modular fashion. That is, basic functions are performed by one task. Only the scheduler task performs queue manipulations and updates the status of a job. Each separate facilitity of the shop is controlled from one main task with the only interaction with other tasks being in the transferral of data through the shared data blocks. The formatting of many messages is performed by one in-core program. And many other functions were separated off and assigned to one task early in the design. This modularity is extremely helpful both in locating and fixing program bugs and in adding new facilities to the system.

Another design feature that continually facilitates making changes to MSIS is the structure of the data blocks on disk as illustrated in Figure 5. As previously explained, each job results in the production of many pattern plates and master masks. There are identifying numbers on all of these plates. By using a table which links the identification to one description block on disk, all the job data can be easily retrieved by tracing through the illustrated ring structure. In the other direction, a job number leads to the job description block, and, using the ring structure, to all information about the job. A single description block is of constant size, and a very large or very complex job only results in more entries in the ring structure. Thus the tasks can handle small and large jobs in the same manner and without wasting disk space. Also, new tasks only need use several basic tables to retrieve any job information.

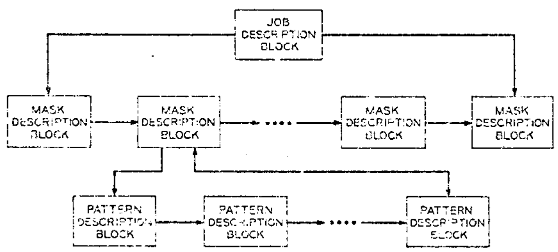

Figure 5. MSIS Data Structure

Since the shop went through periods of using MSIS and not using MSIS, it has been possible to get feedback on the effect MSIS has on shop operation. This feedback has been favorable. The shop produces more under MSIS control, and managers and engineers like the "quickie" reports MSIS can give on the status of the shop or a particular job.

MSIS development is still underway. In the future MSIS will include a data link to a computer controlling a coordinate measuring machine and will thus provide automated inspection capabilities. Inventory facilities for existing masters and available photographic plates are also planned. Even with these additions, MSIS will use a small percentage of the available computer time. In the early stages of MSIS development, it was anticipated that MSIS might be able to work in the background of the PDP-9 used to control the Primary Pattern Generator, and this possibility must still be investigated.