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AUTOMATIC TEST EQUIPMENT FOR ELECTRONIC COMPONENTS

Volume I - Summary Report

by William A. Heffner

Prepared by
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16. Abstract

The summary contains the significant results of a study conducted to define the requirements for an advanced test system for discrete, integrated, and experimental electronic components. A cost-effectiveness analysis of the system application was also performed during the study. The primary focus has been on technology changes and future trends.

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FOREWORD

This report is the product of a six-month study by Martin Marietta Corporation, Denver Division, under Contract NAS12-2045. Mr. Edward Sarkisian, NASA/ERC Automated Techniques Branch, served as Technical Monitor.

The purpose of the study was to define the requirements for an advanced test system for discrete, integrated, and experimental electronic components, and to perform a cost-effectiveness analysis of the system application.

This report contains the significant results of the study. The primary focus has been on technology changes and future trends.

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AUTOMATIC TEST EQUIPMENT FOR ELECTRONIC COMPONENTS

VOLUME I - SUMMARY REPORT

By William A. Heffner
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SUMMARY

This volume summarizes the final report (Volume II), which defines an automatic test facility for NASA/ERC for testing discrete and integrated electronic components. In addition, the facility is to serve as a test bed for algorithms and diagnostic techniques under development by NASA/ERC. Capability for extension of the facility into other testing categories, and use by other NASA centers and industry, has been given consideration.

INTRODUCTION

This report covers an analysis of requirements, candidate configurations, specification of the selected configurations, an acquisition plan, and a cost effectiveness study. Assessments are made of current industry test practices, languages, test equipment standards, and recommendations for additional development activity.

In this report, primary emphasis has been placed on the following aspects of the problem:

1) Computer;
2) Man/machine interface;
3) Test station architecture.

Relatively little emphasis has been placed on:

1) Specific stimuli or measurements;
2) Testing criteria or methods.

From a technical standpoint, today's components are reasonably well served by existing test equipment, specifications, and practices. Problems exist in test data management, the proliferation of semiconductor and integrated circuit types, and the more rarified reliability requirements of space and certain military applications.

Future requirements will be dictated by the unmistakable trends toward medium- and large-scale integration (MSI and LSI). Other pertinent developments are devices based on different physics, and combination electronic/mechanical devices. All of these will make much of the present special-purpose equipment and methodology obsolete. With LSI alone, components will shortly acquire the complexity of yesterday's subsystems -- without the accessibility of the old packaging techniques. Test hardware will continue to be developed to provide the requisite stimulus and monitoring; the real problems will lie in analysis, test definition, meaningful data control, and economics. Test specification, test performance, and fault diagnosis will become too complex for intuitive and manual approaches.

Fortunately, the application of the computer to the test situation permits a series of new and sophisticated approaches to test, diagnostics, criteria, and data handling that can be sufficient to maintain pace with problems.

Much present computer-controlled test equipment, however, represents only a very small step in this direction. For the most part, the computer has been used as the "stepper switch," the patchboard, or the tape controller in test equipment whose architecture and techniques remain essentially unchanged. A better system approach, addressed to the needs of the total testing problem, is needed along with an architecture that will give the computer and its software the proper role. The introduction of the minicomputer has probably delayed, rather than helped, the situation; low price has extended its use, while the limited capabilities have put a ceiling on what can be done in the critical areas of man/machine communication, data management, and test definition and analysis.

For these reasons, we have chosen to emphasize those aspects of an automatic test system that we consider crucial to such future development. We assume that equipment (hardware) will be available to provide the physical interface to the devices when it is needed, and have concentrated on devising a better system approach and architecture.

The test system must also be compatible with present economic and practical constraints. A three-phase, incrementally acquired system has been developed from numerous detailed configurations and tradeoffs. In the initial configuration, a small computer is used in a dedicated configuration with a single test station. The station is general-purpose for a class of test devices. A minimum test language and test monitor is implemented within the installation.

Phase II upgrades the central processor portion of the system to provide long-term expansion capability and greatly increased software power. The test station is retained; additional stations may be added. A language compiler or a meta-compiler is resident within the system. Interfaces with advanced test algoithms and processors, now under development, are possible. Operator interaction during test is provided.

Phase III will provide for multiple remote operations, with an expanded central processor handling local test needs, and those of other, remotely located systems, over low-cost telephone lines. All operations, including testing, translation, and data analysis, may be time-shared from the remote sites through the Test Center. The test station retains the same basic architecture, except that a minicomputer is incorporated into the remote terminals for high-speed test operations. Very powerful software and between-installation data corellation are provided.

This plan may be entered at any point, followed in response to requirements, and terminated at any point. The configuration study defines the above in greater detail.

Sources of Data

Data were derived from NASA personnel directly engaged in testing, a two-day round table conference with eight ERC contractors and grantees, selected industry representatives, and Martin Marietta Denver Division personnel engaged in testing. We have also drawn freely on extensive corporation experience with computerized testing (AAP, Viking, etc). Tape-recorded telephone interviews, on-site appraisals and conferences, and detailed printed questionnaires were all used in developing the data.

Types of Testing

The categorization of testing requirements and practices used in this report was based on operational rather than specification requirements. This categorization is as follows:

1) Receiving inspection - Sample functional testing with occasional parameters or AC testing;

2) Screening - A combination of stress and electrical parameter tests, usually burn-in and/or life in combination with DC parameters, performed 100% on a lot of parts;

3) Qualification - An extensive series of electrical, temperature, and environmental tests, both 100% and sample, designed to verify that a specific part type will meet criteria and properly operate in the usage environment;

4) Reliability testing - A set of electrical and/or stress tests designed to establish part operating history and failure rates;

5) Component manufacturing - Test performed by the component manufacturer to confirm Mil-Spec requirements;

6) Component subassembly testing - Testing performed on a group of individual components that have been assembled to perform some larger function;

7) Experimental - This category is directed toward either the development of techniques for testing and diagnostics or the use of an automatic facility as a tool in developing new devices for technology.

References to type of testing throughout the remainder of this report assume the definitions given above.

Test Equipment

Equipment actively in use at various installations is defined in table I. Analysis of a number of commercially available test sets is given in table II.

TABLE I

UNIQUE OR AUTOMATIC TEST EQUIPMENT USED

	User									
	1	2	3	4	5	6	7	8	9	10
1. Semiautomatic commerical IC tester		X	X			X	X	X		X
2. Semiautomatic commercial transistor tester		X	X			X		X		X
3. Automatic commercial relay tester										X
4. Automatic facility-built IC tester			X							
5. Automatic facility-built discrete-component tester			X							
6. Automatic commercial capacitance bridge						X	X			
7. Automatic commercial multimeter							X			
8. Automatic commerical resistance-capacitance tester										X
9. Electron microscope		X	X							
10. Tap tester			X							
11. Bond puller			X							

TABLE II

COMMERCIALLY AVAILABLE TEST SETS

	LSI	ICs	Transistor	Diode	Resistor	Capacitors	Relays	Maximum pin capability	Tests/sec	Stimulus accuracy, %	Measure accuracy, %	Sequence	Data recording	Program input rate char/sec	Data acces	Program storage	Programing method	Computational	Language
Fairchild																			
5000	X	X	1	1	1	1	1	100	200	0.1→0.2	0.1→0.2	F	Opt		Transient or nonres opt	Disc	Keyboard or opt tape	No	Machine
8000	X	X	1	1	1	1	1	144	10K	1	1	I	Opt		Nonres	Disc or comp	TTY or punched tape	Yes	Machine
E H 4002	2	2	2	2				120	200	.5	1	P	Incr tape		Nonres	Mag core	Keyboard opt tape	No	Machine
Tektronix S-130	2	2	2	2					100	3	3	P			Transient or nonres	Paper tape and disc	Punched tape	No	Machine
AAI 1000		X	1	1	1	1	1	60	180	0.1	0.22 I	P	Opt	10	Transient or nonres	Disc	TTY and punched tape	No	Machine (mnemonic)
Teradyne J259	3	3	3	3	1	1	1	63 Spec arr opt	200	0.15→0.5	0.15-V 0.25-I I	I	Mag or paper tape		Nonres	Mag core		Yes	Machine
Texas Instruments 553	X	X	1	1	1	1	1	148	50	0.05→2	0.2→ 3.5	P	Opt	1000	Nonres	Mag core	TTY and punched tape	Yes	Machine

The low level of computer use in much of the equipment is striking, in view of the considerable interest and literature currently being generated.

Component manufacturers use automatic test equipment almost exclusively. The cost of such equipment is not trivial. For the more complex devices, the control circuitry in the test station becomes a significant cost element. Few installations will have funding available to duplicate such equipment for each new kind of part as it reaches common use. (To a large extent, this is what is happening today; installations now investing several hundred thousand dollars in an automatic integrated circuit test system will discover that they must additionally invest half again as much in a test system for LSI.)

General Comments and Problems

If there were a single major problem to be extracted from the entire requirements survey, it would be in the area of data management. This was mentioned explicitly by more contacts than any other single problem.

The tests considered most effective by the survey contacts are heavily oriented to environmental (stress) testing. Electrical testing is, of course, necessary to verify that the device performs during, or after, stress application; nevertheless, today's electrical tests are obviously not considered sufficient to verify device integrity by themselves.

Establishment of standardized testing practices, parameters, and stresses for increasingly complex and specialized circuits, such as LSI, promises to be a difficult and drawn-out proposition.

Techniques for detecting faulty junctions or "components" within the LSI chip must be developed for LSI to become economically practical. This is not in reference to user repair but to the ability to fabricate a working chip. This appears to be the most difficult problem associated with LSI testing. Almost certainly, sophisticated use of the computer will be necessary. A potential development path that is often overlooked today is that of linear LSI devices. In all but two cases, the survey contacts assumed that LSI defined purely digital circuitry. The recent introduction of complex analog circuitry in single monolithic devices does not support this assumption. Linear LSI devices will make extreme demands on the flexibility of test equipment.

Concentration on LSI, however, is likely to leave one unprepared for other new directions in components, such as optical circuitry, and active electromechanical devices.

REQUIREMENTS

The "Requirements" section of Volume II develops the required characteristics of the automatic test system from the data obtained in the requirements survey. The method used follows that described by Heffner* and is detailed more fully in Volume II of this report.

Table III lists specific weighted requirements by category of testing, and table IV summarizes the characteristics needed to meet the requirements.

The characteristics, once established, partially determine the system architecture and configuration. Nonresident data, for example, define a relatively efficient data output device, such as punched cards, while locally resident data define a secondary storage medium, such as a drum.

Computational/Noncomputational

The system must be computational. Data analysis, logical operations for complex large-scale arrays, and minimization of special-purpose station hardware dictate this requirement.

Data Access

The method of test data handling will vary with the type of test. In the initial system uses, nonresident data may be sufficient; as diagnostic capabilities are developed, local data access will be needed. Some degree of global data access will be required for reliability usage.

It is recommended that initial implementation provide local data access. The very slow output provided by punched paper tape will be an unnecessary burden in many test runs when the decision on whether the data are significant and should be retained may not be made until after test completion.

Providing local data access permits this decision (and consequent investment in time) to be made on test completion. Later phases of the system should provide global data access to the extent necessary to detect trends or correlations necessary for real time operation.

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*W. A. Heffner: Automatic Test - An Overview and Classification. Presented to the AAS/ORSA Joint National Conference, Denver, Colorado, June 1969.

TABLE III

REQUIREMENTS BY TYPE OF TESTING

Type of testing	Language (a)			Interaction (b)	Data (c)				Malfunction isolation (d)	Batch Operation (e)	Interface (f)
	New tests	Flex	Power		Quan	Rate	Dur	Comp			
Receiving inspection	3	1	1	1	3	3	S	1-2	0	1	0
Screening	2	1	1	2	2	1	L	1-2	0	1	0
Qualification	2	2	2	2	2	1	L	2	0	2	0
Reliability	1	2	2	2	4	2-4	L	4	0	2	1
Component in-process	2	2	2	1	1-3	4	S	1	0	1	2
Assembly in-process	4	3	3	2	2	2	S	2	3	4	1
Laboratory automation	2	3	3	3	2	1-3	S-L	1-4	1	3	0
Experimental	4	4	4	4	2	1-4	S-L	2-4	2	4	3

[a]Language:
New tests - Frequency of writing new programs;
Flex - Variety of test functions;
Power - Need for simple expression of complex functions.

[b]Interaction - Degree of on-line operator control, changes, and decisions required.

[c]Data:
Quan - Relative daily output of data;
Rate - Required speed of data output;
Dur - Period of duration of continuous data output -- S = short duration (less than 1/2 hr)
L = long duration (more than 1/2 hr);
Comp - Complexity of data analysis required on-line.

[d]Malfunction isolation - Level of malfunction isolation capability required.

[e]Batch operation:
Percentage of use for batch processing (program translation, etc) --
0 = 5%, 4 = 80%.

[f]Interface - Level of requirement for interfacing with other computer programs, such as computer-aided design.

TABLE IV

REQUIRED CHARACTERISTICS

Type of testing	Analysis method	Data access	Program method	Conditional execution	Relation to other systems	Test hardware configuration	Test control	Language
Receiving inspection	Either	Transient nonresident	Stored	Data, breakpoint	Free-standing, dependent	Fixed	Static	Macro
Screening	Computer	Global	Stored	Data, breakpoint	Dependent	Fixed	Either	Macro
Reliability	Computer	Global	Stored	Interactive	Network, dependent	Fixed	Dynamic	Compiler
In-process assembly	Computer	Resident	Stored	Interactive	Free-standing, independent	Either	Dynamic	Compiler
Depot	Computer	Resident	Stored	Interactive	Free-standing, dependent	Either	Dynamic	Macro, compiler
Experimental	Computer	Global	Stored	Interactive	Independent	Either	Dynamic	Compiler

Program Method

Externally programed devices, while suitable for rigid sequence operations such as numerical control, some types of production testing, and other operations requiring a very low level of operator participation, are unsuited for the majority of test categories in present applications, and totally unsuitable as solutions to future problems and requirements. Stored programed systems providing looping, branching, and program modification capability, with a potential for a high degree of operator interaction, are required.

Conditional Execution

Fixed sequence systems may be disposed of with the comments above. For the ERC application, some degree of interaction is a fundamental requirement from the beginning. In fact, interaction is probably more significant in the beginning stages than in the final configurations; the otherwise limited central processor and software will impose very severe penalties in time, when every change necessitates a reprocessing of a predefined program or experiment.

Free-Standing/Network

No firm requirement can be established for on-line interconnection with other systems, especially in the earlier phases. The choice is not clear cut; high data output operations such as continuous monitoring during reliability testing pose data management problems regardless of the acquisition techniques. Because of economic considerations, it is assumed that a free-standing system will serve the purpose initially, with local reduction, correlation, or trend detection to some level. Suitable output media for residual data will be provided as required.

Independent/Dependent

This characteristic is probably the most difficult of the list to establish. The decision is primarily economic and operational. The independent system offers numerous operational advantages if an adequate processing capability is available. On the other hand, the apparent initial cost advantage of a dependent system can rapidly disappear in conversion costs when either the supporting or the test installation is changed.

The recommendation is that all operations directly affecting the test itself (such as program translation) should be included within the system as independent functions; operations that do not directly support the test, such as posttest data analysis, formatting, or filing can be deferred to a supporting installation on the basis of individual economic tradeoffs.

Fixed/Variable

There is little advantage to a variable configuration system where only a single or several test stations are used. The primary advantage to a variable configuration is attained when a large number of special-purpose test channels may be circulated among a number of test stations (to avoid providing the total number of test channels in each test station). This is normally characteristic of production or depot test operations rather than the classes of testing addressed by this study. A fixed configuration system is recommended.

Static/Dynamic

A significant potential advantage of the use of a computer lies in the minimization of special-purpose test equipment and hardware solutions to problems that may be easily handled by the computer. In this sense, dynamic control by the computer of the test should most definitely be a characteristic of the system.

This characteristic affects the test station, the input/output control, the method of command and result access, and the conceptual structure of the test monitor and test language. The primary hardware implication is in terms of speed, i.e., the bandwidth of the test unit/test program communication loop. Careful design and sound conceptual structure is most important; there is little if any penalty in terms of hardware cost. Therefore, full dynamic operation has been assumed as a characteristic of the system even though initially the full use of this capability may not be required. The economic advantage lies with building the capability into the system architecture from the initial stages, even at the price of potentially somewhat higher software and system integration cost. Conversion later to provide such capability can be prohibitive. The long-term economic advantages in minimization of special-purpose hardware cost and technical obsolescence are overriding.

Test Hardware

This characteristic affects the test station, the input/output control, the method of command and result access, and the conceptual structure of the test monitor and test language. The primary hardware implication is in terms of speed, i.e., the bandwidth of the test unit/test program communication loop. Careful design and sound conceptual structure is most important; there is little if any penalty in terms of hardware cost. Therefore, full dynamic operation has been assumed as a characteristic of the system even though the initial use may not require full use of this capability. Conversion later to provide such capability can be prohibitive. The long-term economic advantages in minimization of special-purpose hardware cost and technical obsolescence are overriding.

Major Configurations

From the standpoint of general system architecture, three major configurations are presently possible:

1) Dedicated;
2) Time-sharing;
3) Master/slave.

Theoretically, these variations in architecture do not affect or constrain any characteristics of the system. However, in practical terms a very significant interrelationship comes into play when cost is introduced. The dedicated configuration can certainly be given processing capability as powerful as a time-sharing configuration. It will then be inefficient in terms of computer utilization and, in many applications, not cost effective. The processing capability will either be scaled down, which will change the characteristics, or additional test interfaces will be added and time-shared.

If a dedicated system is designed initially as a subset of a time-shared system, there is a relatively small penalty to pay in later conversion to time-sharing, and it is probably advantageous to begin with a dedicated system in the initial development stages.

We have discovered no requirement within the scope of this study for which the data rates or analysis complexities are such that they cannot be handled by an efficient time-shared system.

If overhead is properly minimized and buffered IO is used exclusively, the system does not become computer-limited until almost the maximum expansion capability has been achieved. Therefore, there appears little need for a master/slave configuration.

Recommendations for the major system configuration are as follows:

1) The initial implementation should be dedicated, but designed as a subset of a time-shared configuration;

2) Additional test stations may be handled on a plug-in-when-needed basis until usage conflicts become intolerable. At that point, the system should be converted to time-sharing;

3) The system should be capable of eventually driving multiple remote installations through a remote interface for both test and batch operations.

CONFIGURATIONS

The configuration study defined a series of candidate configurations in response to a series of test requirements. The test requirements selected were functional, parametric, and reliability testing of digital large-scale arrays. Each configuration was evaluated and priced. It was assumed desirable to start with a minimum configuration and expand; growth paths were plotted as a function of capability against cost.

As a result of this study, uneconomic configurations and growth paths are identified, and decision criteria are developed for use by the Technical Monitor. Final data are presented in such a way that ERC can select the initial implementation level and ultimate "destination" of the system with a clear understanding of the initial and final costs and technical capabilities.

Language-Translation

A separate study of test language translator schemes was performed and related to the system configurations. Table V compares translator characteristics.

Recommendations for language translators are as follows:

1) Minimum system (A1 or C1) - The interpreter offers the best compromise because of the on-line flexibility and simplicity of development and use;

2) Medium-size system (C1′) - A procedure processor, if available for the computer, provides high flexibility in language and high efficiency of object code for low application cost.

An ultimate system might well be one that combines a powerful and flexible translator with an interpreter. In this system the translator would generate, not binary machine code, but a simplified symbolic source language at the macro level. This symbolic code then becomes an input to the interpreter. This approach would offer the power that an interpreter alone can not achieve, and the on-line change capability that a pre-translator can not offer. In addition, the intermediate (simplified symbolic) output of the translator would be accessible to the test engineer, so that critical time sequences or other problems demanding tight control of the generated code could be examined and rearranged before test execution.

TABLE V

TRANSLATOR CHARACTERISTICS

Category	Type of Translator				
	L1 interpreter	L2 macro-processor	L5 meta-compiler	L3 procedure processor	L4 compiler
General					
Capability of language	0	0	1-3	1	1-3
Expandability	2	2	1	2	0
Conditional tests	0	0	3	1	3
Convertability (to other digital comp)	1	2	3	3	0
Ease of use	3	1	2	1	2-3
Ease of debugging	3	2	1	1	1
Reporting/documentation possibilities	0	0	1	1	2
"In-line" assembly level instructions	0	3	3	3	2
"Leveling" and "nesting" of procedures?	0	0	2	3	3
	9	10	18	16	15
Development/characteristics - translation					
Core requirements (translation)	4 000	6 000 to 8 000	20 000 to 48 000	12 000 to 16 000	16 000
Implementation on mini computer	Yes	Yes	No	Limited	No
Development	19 MM	15 MM[a]	80 MM	15 MM[a]	40 MM+
Characteristics - test execution					
Core requirements (overhead for first execution only)	2 000 to 6 000	0	0	0	0
Basic subroutines (linkage)	Closed	Open	Both	Both	Both
Execution efficiency	1	2	1	3	1
Translation efficiency	3	3	1	2	1
On-line interaction	3	2	1	2	1
On-line modification in source	3	1	0	0	0
Adaptability to time sharing	0	2	1	2	1
Error diagnostics and debugging aids	1	0	2	2	3
	8	7	5	9	6

[a]Assumes basic translator available.

System Configuration

The system configurations are listed with appropriate comments but are not presented in detail in this summary volume. The configurations are summarized in figure 1 and table VI.

Growth paths and cost effectiveness of the configurations are plotted in figure 2.

The horizontal axis of figure 2 is a relative measure of system capability (not test capability). The rating for each configuration is a sum of the individual ratings in Table VI.

The vertical axis in figure 2 is the cumulated expenditure for hardware and basic software.

Each configuration is plotted against its performance rating and cumulated expenditure, in arriving at that configuration. The most economic path is A1 through C4. This path is quite efficient. Power vs expenditure is nearly linear, no matter where the path is entered.

From the cumulative cost standpoint alone, the obvious best performance is C1′-C4. However, other considerations intervene. The most obvious is the ability to support and economically use the more expensive unit in the initial stages of an overall development program. It takes time to develop skills, applications, and demand; and while demand is historically underestimated for computer installations, a case can be made for starting at a lower level, even if the cumulative cost is ultimately higher. Secondly, one must be fully convinced of the technique and applicability. It is, however, interesting that lower early expenditures often lead to very significantly higher total program cost. One might follow the A1-B1-B2 path, assured in his small first investment and still unpainful later deltas, until it was too late to economically recover. From such instances come the familiar horror stories of "conversion costs." At least some of these (apochryphal) situations are made, not born.

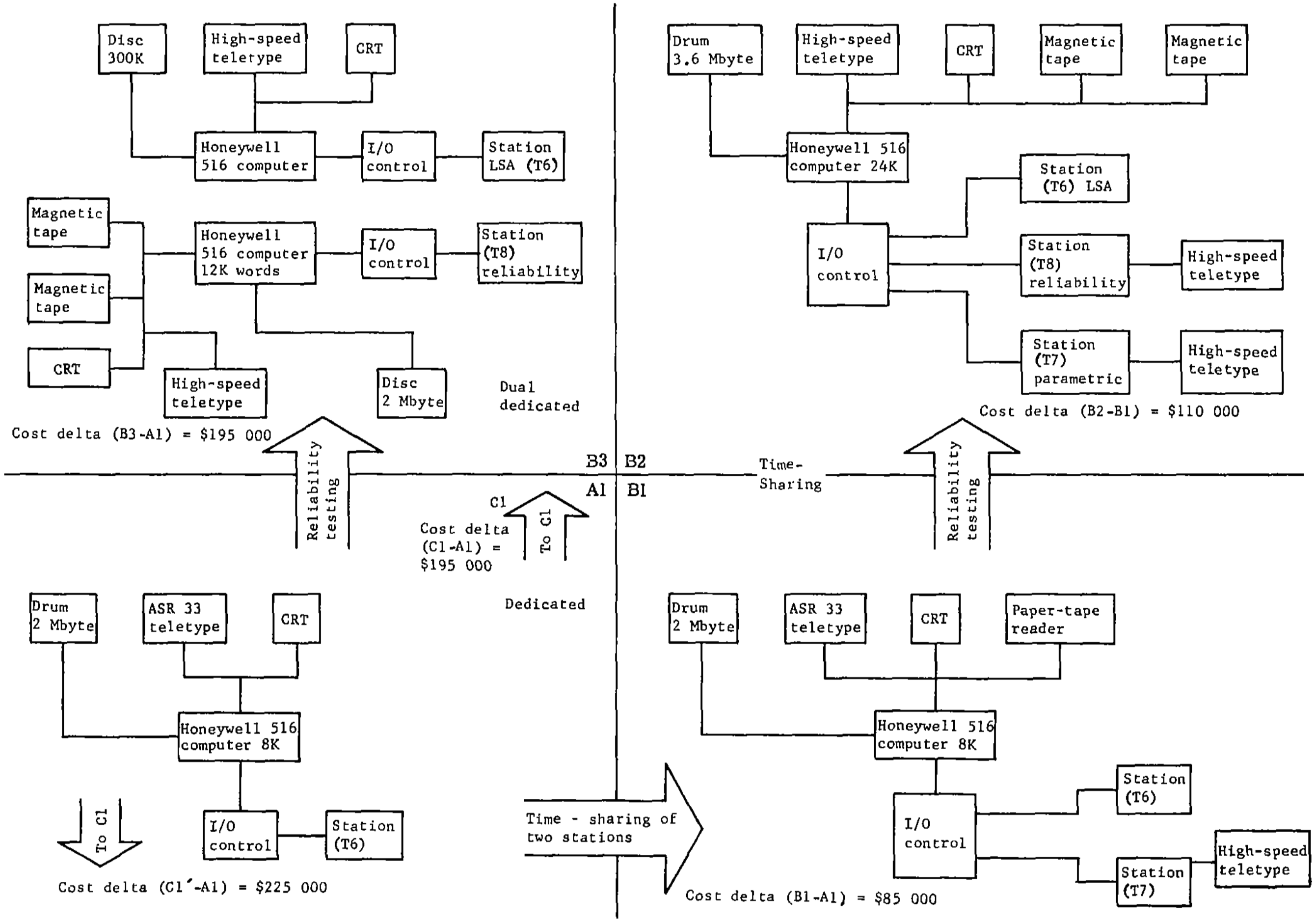


Figure 1.- System Configuration Graphic Summary

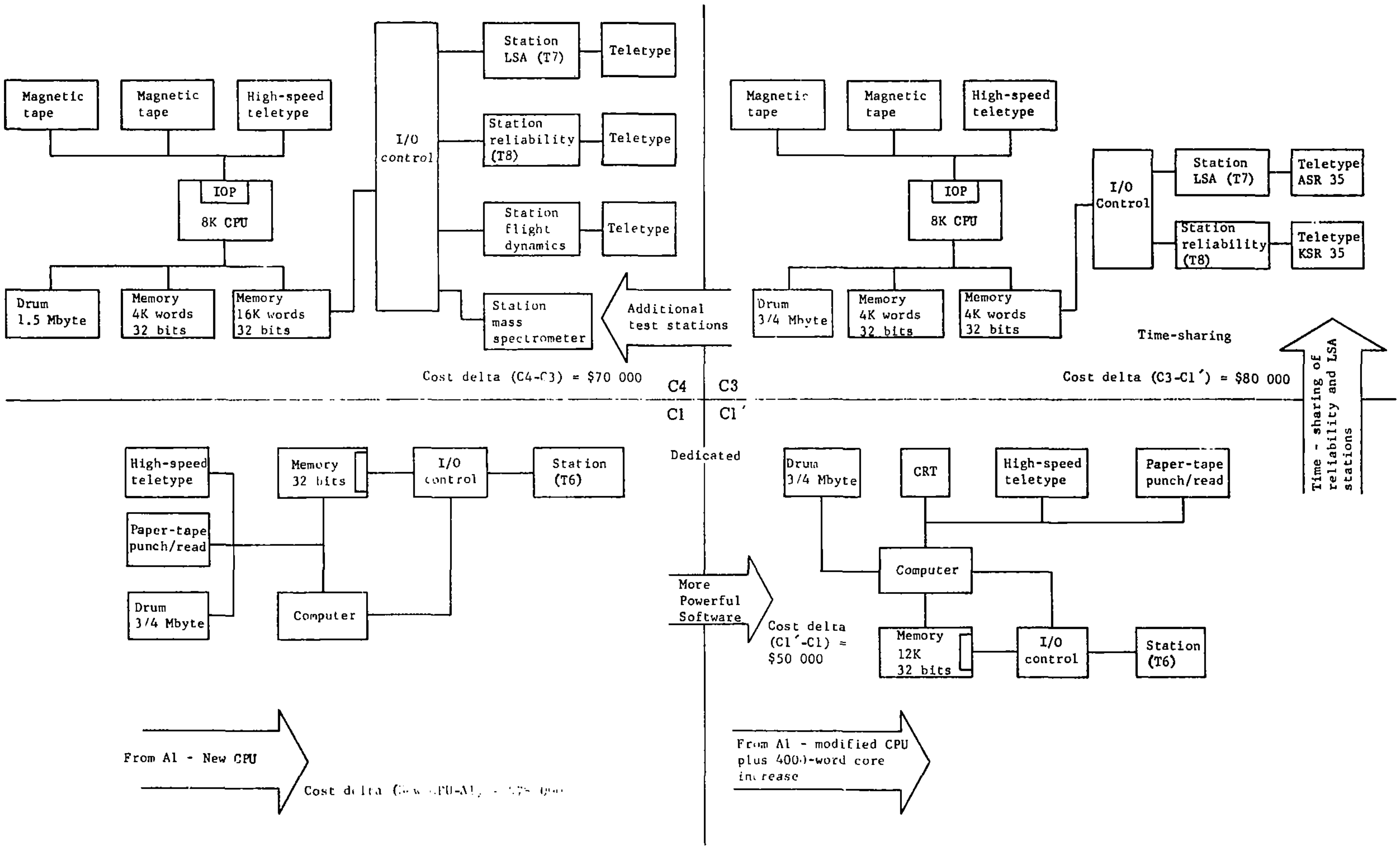


Figure 1.- Concluded

TABLE VI

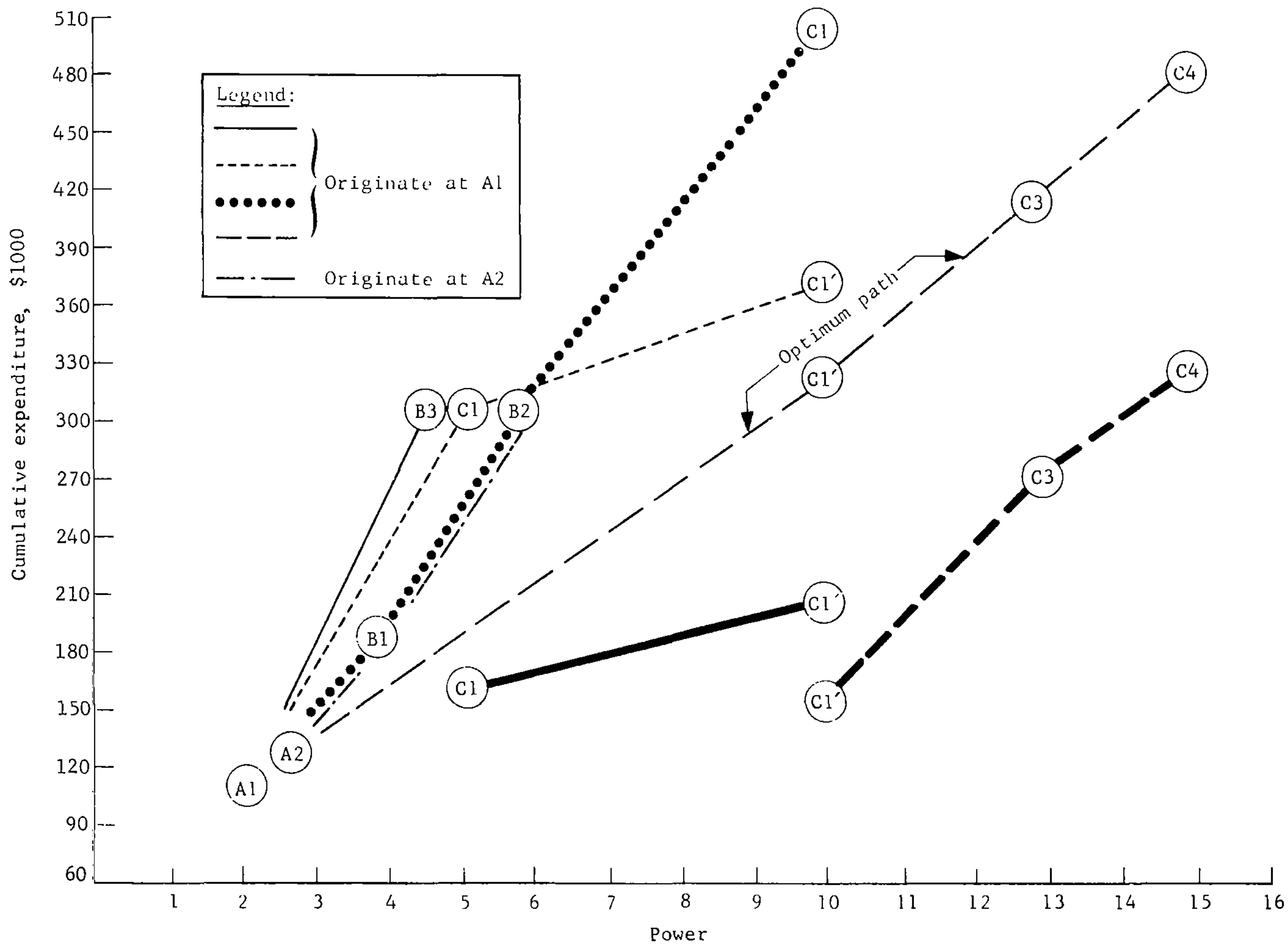
SYSTEM CONFIGURATION SUMMARY

Configuration	Description	Detailed characteristics	Test language power	Operating system power	STR	O_I	T_S
A1	Minimum dedicated system for functional test of large-scale arrays (LSA)	Minimum configuration using small-scale CPU equipment in dedicated configuration to drive single test station Minimum test language configuration and test monitor operate within system Usage is experimental functional testing of digital LSA up to 100 logic nodes and 150 interface points	1	0	0	0	2
A2	Configuration A1 with addition of parametric test capability for digital LSA	The minimum CPU, language, and monitor of A1 retained; parametric test capability requires only addition of analog stimulus and measurement test channels to test station and incorporation of corresponding statements in test language	1	0	0	0	2
B1	Minimum system for time-sharing test stations	This configuration adds capability for time-sharing two stations to dedicated system of A1; addition of time-sharing has no effect on test station or computer hardware itself	1	0	1	0	4
B2	Addition of reliability testing	This configuration adds one typical new requirement (reliability testing program similar to that contemplated by ERC's Device Research Branch). Modular increments to memory and I/O control implemented to service additional station; addition of magnetic tape. functions to monitor and language, and second high-speed teletype	1	0	1	1	6
B3	Dual configuration for addition of reliability testing	This configuration examines cost and practicality of independent system (similar to A1) for reliability testing; because hardware essentially duplicated. variable of interest here is savings in development time	1	0	5	1	4
B4	Time-shared LSA and parametric testing with supporting installation for software	This configuration implements language translator and other software on separate existing installation; test system used only for test; other functions remain similar to B1					

TABLE VI.- Concluded

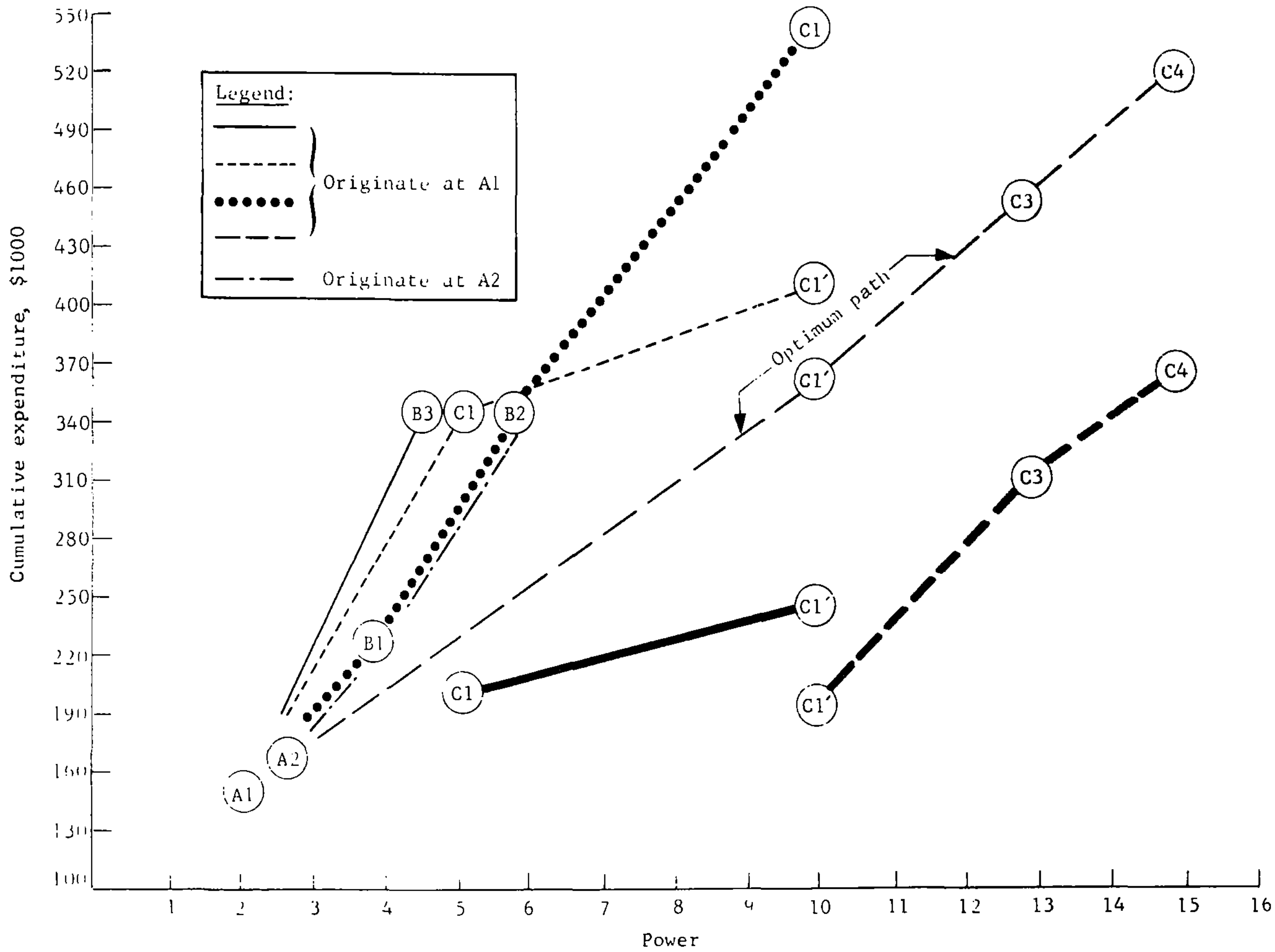
SYSTEM CONFIGURATION SUMMARY

Configuration	Description	Detailed characteristics	Test language power	Operating system power	STR	O_I	T_S
C1	Third-generation CPU in dedicated system for functional test of digital LSA	This configuration similar to A1, except that "stripped-down" version of computer capable of expansion to medium- or large-scale application used for central processor; minimum peripherals, basic operating system, and simple interpretive language identical to A1	1	1	1	1	
C1	Background'foreground system for dedicated test of digital LSA	This system identical to C1 except 4000-word increase in core size permits translation concurrent with testing and a relatively powerful language processor (L3); rest of configuration essentially same	3	2	2	2	
C3	Background/foreground system for time-sharing of reliability and LSA test stations	This configuration converts C1 to time-sharing and adds test station and software for reliability testing. CPU hardware in core size and addition of magnetic tape; I/O control modified for time-sharing; software changes include modification of test monitor for time-sharing and addition of new test and data analysis functions to test monitor and language; additional capabilities added to the operating system	3	2	3	3	
C4	Expansion of C3 time-sharing system to additional users and addition of modern channels	The capability of C3 time-sharing system to accept additional test stations, and consequent increase in batch processing load, is tested here; two diverse applications selected: (1) typical laboratory automation application (mass spectrometer), and (2) typical developmental application (flight dynamics)					
		Only hardware expansion is modular increase in drum size for data, and program storage and software extensions for new uses					
D1	Remote user time-sharing system	Full remote user capability provided, including remote batch I/O; dedicated "minicomputer" added to test terminal for local control and data compression; CPU expanded and next higher level operating system installed to provide control of remote batch terminals	3	3	4	3	



(a) CPU available

Figure 2.- Alternative Growth Path Cost Comparison



(b) CPU not available

Figure 2.- Concluded

Conclusions

Conclusions are as follows:

1) An initial development phase using small-scale computer hardware can be economically implemented;

2) Maximum expansion of this initial configuration provides only limited potential. This is due to the inherent limitations of a small-scale computer;

3) Conversion to a suitable medium-scale computer used in a time-sharing mode can provide considerable growth capacity;

4) A very significant cost penalty can ultimately result if the initial configuration and the conversion are not properly controlled;

5) Adherence to the optimum growth path in figure 2 can minimize the expansion "loss" to less than 20% of final cost;

6) Expansion beyond the needs of ERC Automated Techniques Branch alone appears technically and economically feasible. This is defined as Phase III and provides for servicing of complete remote installations by means of a centrally located, expanded, Phase II central processor.

SPECIFICATIONS

Each augmentation of the system shall, ideally, be a superset of the previous system. Subsystems should be as independent of each other as possible so that expansion or change in one element (e.g., the computer) reflects minimally into other subsystems (e.g., the test station). The basic system design should be independent of technical test parameters (stimulus and monitor capability) as far as possible, and the system should exhibit the characteristics defined in the requirements analysis section. The foregoing recommendations are depicted in figure 3.

Phase I - Startup

The objective of this phase is to "get in business," that is, to produce a working minimum system for functional testing of a single class of devices (large-scale arrays). Some compromise is made in the area of software and the test language because the Phase I software investment will be largely lost when progressing to Phase II. The restrictions imposed by a limited central processor also force software compromises.

Phase II - Growth

The objective of Phase II is to establish a system that is expandible to any foreseeable ERC need of the next five years. The first implementation will provide a minimum-configuration, third-generation central processor. The test stations are carried over from Phase I. An operating system is introduced, and a more powerful language provided.

The initial implementation of Phase II will be such that later modular expansion to the following capabilities will be possible:

1) Time-sharing of multiple test stations;
2) Powerful test language;
3) Sophisticated data analysis and management;
4) Foreground/background operation (minimizes conflict of testing and language translation);
5) System capability for any test category defined in the "Requirements Definition" section of Volume II.

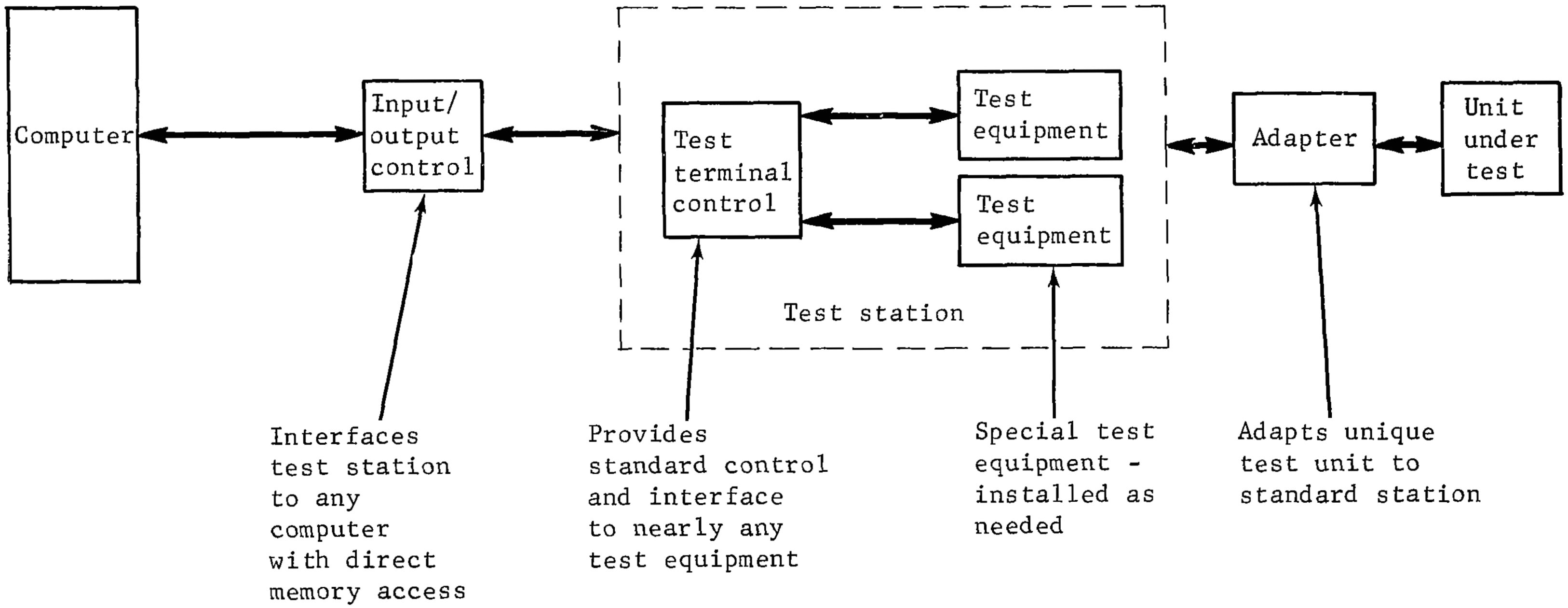


Figure 3.- System Block Diagram

Phase III - Exploitation

The objective of this phase is to exploit, both technically and economically, the base developed during Phase II. The central processor is modularly expanded to provide time-sharing test and batch service to other users (who may be widely scattered); users may share in the amortization of common equipment and software at a very significant cost savings. Very advanced test and data management techniques are possible, including:

1) A network of common test programs and algorithms;
2) A common test data base;
3) Powerful language and computation capability;
4) User communication via the central location, for real-time data correlations and similar cross-use purposes.

The test station and input/output control are common to all phases. The central processor, operating system, and test language translator are each specified for Phase I, II, and III.

Test Station

Analysis of the test situation indicates that many functions associated with control, sequencing, timing, and housekeeping are common to almost any visualizable test. Other functions associated with stimulus and measurement values, levels, and dynamics can be standardized to some extent, but are, for the most part, highly subject to change.

The basic concept developed for the test station is:

1) To provide a common station control section for standard functions;
2) To provide a series of modular test channels, each serving a particular stimulus or monitor function, which are controlled and serviced by the standard control section and provide a standard interface to it;
3) To use a simple unique adapter between the test channels and the test unit itself, to provide special loads, test unit connection, and other functions unique to a specific test article;

4) To make the test station computer-independent by providing a separate, small I/O control unit that will adapt the computer to the standard test station control interface, thus limiting the impact of different computers on the test stations to a single, small device.

Detailed specifications for test station, input/output control, central processor, and software are given in Volume II of this report.

COST EFFECTIVENESS STUDY

GENERAL

The approach selected for the cost effectiveness study is to compare the costs of conventional test equipment with the costs of the test system specified in this report, when both are used in a typical component test situation. The study includes initial costs and projections to 1975.

The term "conventional" used in this section refers to the standard automatic test equipment available commercially. It is generally special-purpose, in that an item of equipment, including the computer, will test one class of components (such as integrated circuits). The term "specified" refers to the system defined in this report. It is characterized by multiple use of the computer and other common functions to control a variety of smaller, standard test equipment items for any class of components.

Organization

The organization of the study is as follows:

1) The installation is baselined in terms of present (conventional) equipment and staffing costs;
2) These are then projected to 1975;
3) Cost of conversion to the equipment specified in this report in 1970 is estimated, and growth costs are projected through 1975;
4) Conventional and specified system costs are then converted to a per part dollar test cost. These two figures may be used to estimate the effectiveness of the two systems for any normal R&D project, by using a "parts per $1,000,000 contract value" derived from several typical R&D hardware programs.

Table VII summarizes the cost effectiveness study. Figure 4 is a plot of total cumulative costs, and figure 5 indicates test requirements and capabilities.

TABLE VII

COST EFFECTIVENESS SUMMARY

Item	Conventional system	Specified system	Difference
Equipment, $			
1. Original investment	272 031	272 031	0
2. 1969 investment (cum)	570 557	572 031	1 474
3. 1972 projected investment (cum)	869 083	831 031	-38 052
4. 1975 projected investment (cum)	1 466 135	970 000	-496 135
Equipment maintenance, $			
1. 1969 annual cost	82 900	35 270	-47 630
2. 1972 projected cost (cum)	429 250	190 950	-238 300
3. 1975 projected cost (cum)	1 048 250	484 495	-563 755
Personnel, $			
1. 1969 annual cost	327 000	163 946	-163 054
2. 1972 projected cost (cum)	1 650 692	829 046	-821 646
3. 1975 projected cost (cum)	3 640 980	1 851 533	-1 789 447
Total cumulative cost, $			
1. 1969 annual cost	980 457	771 247	-209 210
2. 1972 projected cost	2 949 025	1 851 027	-1 097 998
3. 1975 projected cost	6 155 365	3 426 059	2 729 306
Capability			
1. 1969 status			
People	19	8	-11
Days	3 971	1 672	-2 299
2. 1972 projected			
People	27.3	11.5	-11.5
Days	5 705.7	2 403.5	-3 302.2
3. 1975 projected			
People	36.5	15.1	-20.5
Days	6 387	3 155.9	-3 231.1
Test cost per component, $			
1. 1969 cost per unit	2.02	1.58	-0.44
2. 1975 cost per unit	6.70	3.73	-2.54
Test cost factors			
1. Present (1969)	K = 3 020	K = 2 365	
2. Projected (1975)	K = 10 000	K = 5 580	

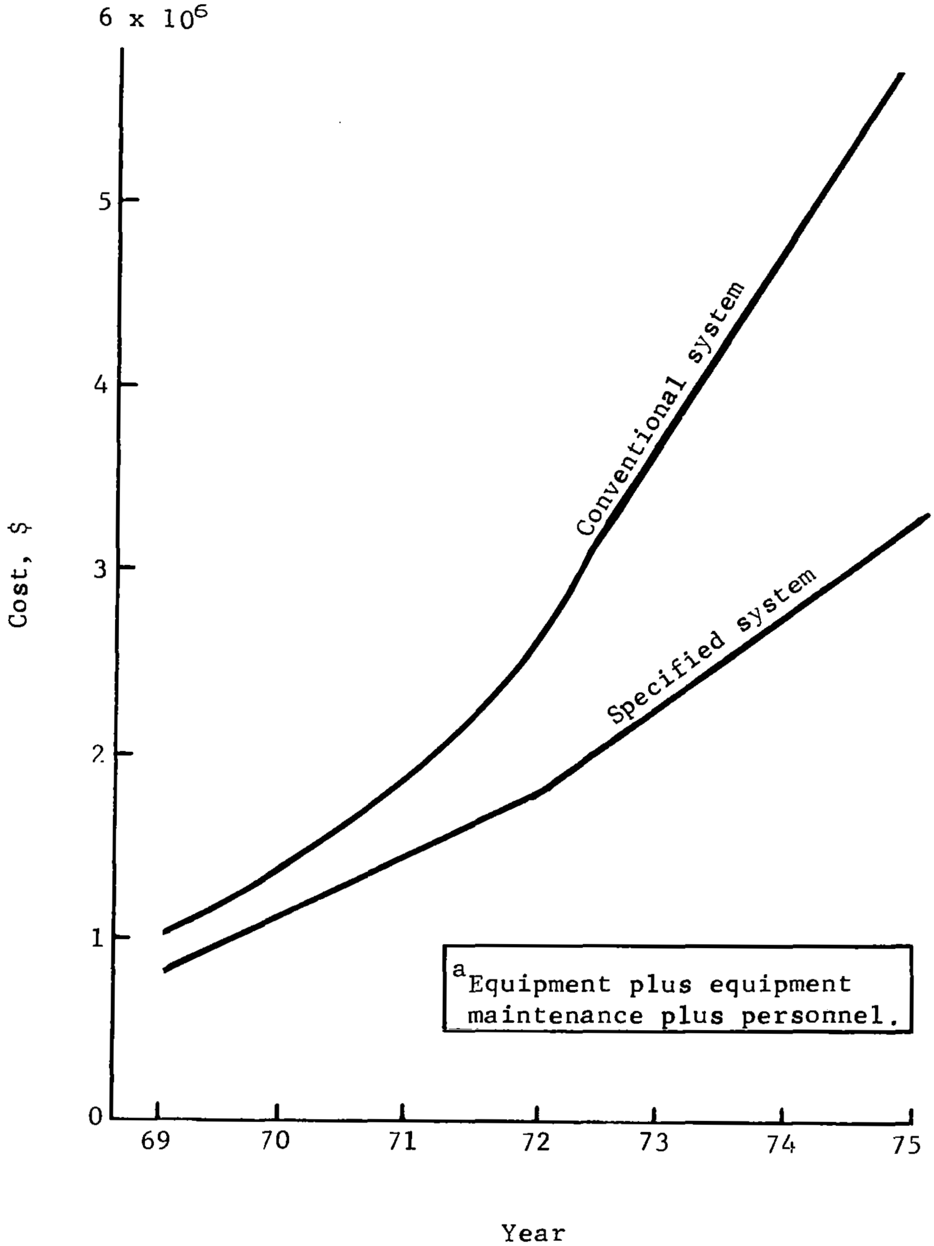
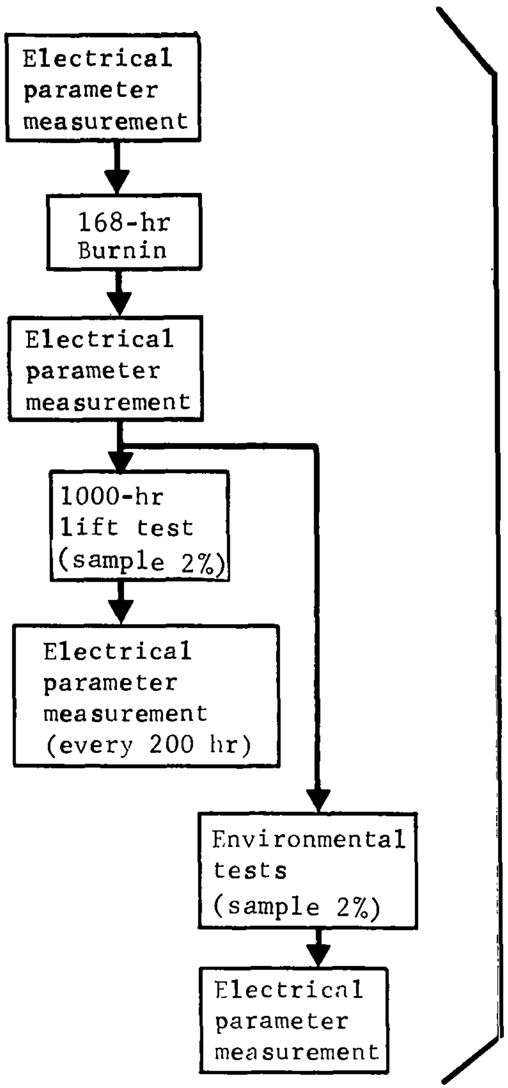


Figure 4.- Total Cumulative Costs[a]



Data reduction	Conventional system	Specified system
Tolerance	X	X
Delta limit calculation	X	X
Percent rejection	X	X
Vendor data review	Overview	Detailed
Parameter distribution	0	X
Correlation technique	0	X
Automatic	0	X
Cross	0	X
Historical	0	X

Legend:
X = performs
0 = does not perform

Figure 5.- Test Requirements and Capabilities

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