

CHAPTER 2

Product Selection Guide

THE 9900 FAMILY – WHAT IS IT?

The 9900 Family is a compatible set of microprocessors, microcomputers, microcomputer modules, and minicomputers. It is supported with peripheral devices, development systems, and software. It provides a designer with a system solution having built-in protection against technological obsolescence. The family features true software compatibility, I/O bus compatibility and price/performance ratios which encompass a wide range of applications. The family is designed with a unique flexible architecture to allow technological changes to be easily incorporated while minimizing the impact these changes have on an overall system design.

FAMILY OVERVIEW

THE HARDWARE FAMILY

Figure 2-1 is a diagram of the 9900 Family members. The spectrum of microprocessors and microcomputer products available in a variety of formats is shown in *Figures 2-2* and *2-3*. In the first part of *Figure 2-1*, the microprocessors or microcomputers are combined with microcomputer support components (*Figure 2-3*) to form systems. These systems also include I/O interface, read-only and random access memory, and additional support components such as timing circuits and expanded memory decode .

The family also includes microcomputer board modules containing the 9900 microprocessors and peripheral components (*Figure 2-4*). As shown in the second part of *Figure 2-1*, these modules can be used for product evaluation, combined for system development or applied directly as end equipment components.

When applications require minicomputers, completely assembled units can be purchased and installed. The software will be fully compatible with any associated microprocessor and microcomputer system. *Figure 2-5* gives a brief overview of the minicomputers.

These three levels of compatible hardware — the TMS9900 family parts, the TM990 microcomputer modules, and the 990 minicomputers — provide the flexibility to obtain an optimum match with the user's system application.

THE SOFTWARE AND DEVELOPMENT SYSTEMS SUPPORT

New products cannot be made without design, development, test and debug. Development support for all of the levels is shown in *Figure 2-1*, including:

- A. Product documentation
- B. Software (or firmware)
- C. Software development systems
- D. Prototyping systems.

Software and development and prototyping systems are outlined in *Figure 2-6*.

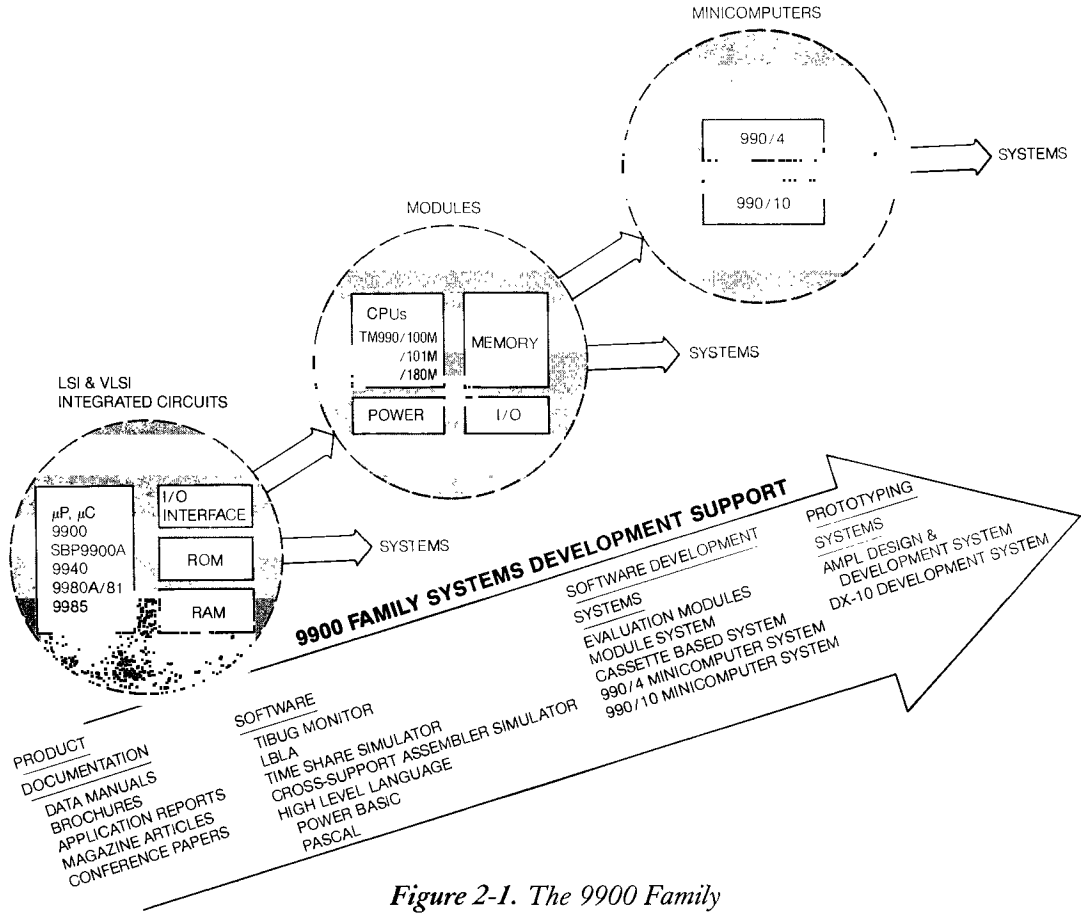


Figure 2-1. The 9900 Family

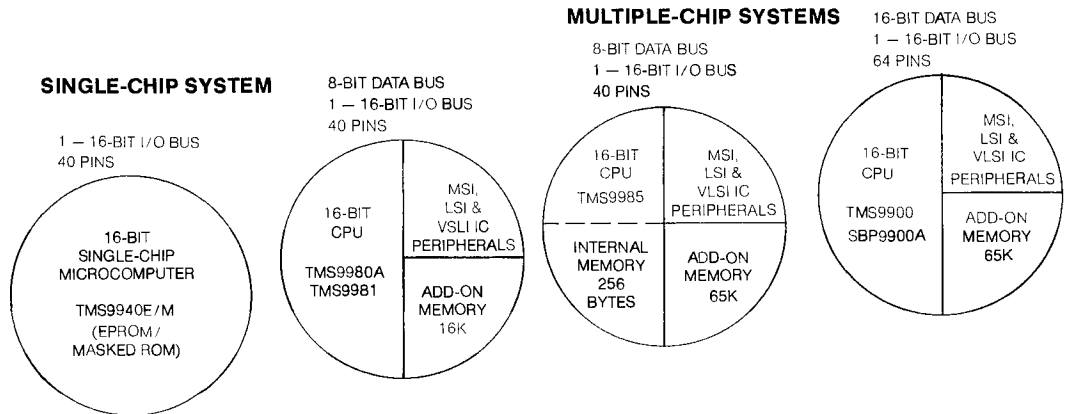


Figure 2-2. 9900 Family CPUs

CPU's

TMS9900	NMOS 16-Bit Microprocessor, 64 Pins
TMS9900-40	Higher Frequency Version 9900
SBP9900A	PL Extended Temperature Range 9900
TMS9980A/ 9981	40-Pin, NMOS 16-Bit Microprocessor with 8-Bit Data Bus. 9981 has XTAL Oscillator
TMS9985	40-Pin, NMOS 16-Bit Microprocessor with Single 5V Supply and 256-Bits of RAM
TMS9940E	40-Pin, NMOS Single Chip Microcomputer, EPROM Version
TMS9940M	40-Pin, NMOS Single Chip Microcomputer, Mask Version

PERIPHERAL DEVICES

TMS9901	Programmable Systems Interface	TMS9914	GPIB Adapter
TMS9901-40	Higher Frequency Version of 9901	TMS9915	Dynamic RAM Controller Chip Set
TMS9902	Asynchronous Communications Controller	TMS9916	92K Magnetic Bubble Memory Controller
TMS9902-40	Higher Frequency Version of 9902	TMS9922	250K Magnetic Bubble Controller
TMS9903	Synchronous Communications Controller	TMS9923	250K Magnetic Bubble Controller
TMS9904	4-Phase Clock Driver	TMS9927	Video Timer/Controller
TMS9905	8 to 1 Multiplexer	TMS9932	Combination ROM/RAM Memory
TMS9906	8-Bit Latch	SBP9960	I/O Expander
TMS9907	8 to 3 Priority Encoder	SBP9961	Interrupt-Controller/Timer
TMS9908	8 to 3 Priority Encoder w/Tri-State Outputs	SBP9964	SBP9900A Timing Generator
TMS9909	Floppy Disk Controller	SBP9965	Peripheral Interface Adapter
TMS9911	Direct Memory Access Controller		

ADD-ON MEMORY

ROMS	EPROMS		DYNAMIC RAMS	
TMS4700—1024 X 8	TMS2508	—1024 X 8	TMS4027—4096 X 1	
*TMS4710—1024 X 8	TMS2708	—1024 X 8	TMS4050—4096 X 1	
TMS4732—4096 X 8	TMS27L08	—1024 X 8	TMS4051—4096 X 1	
SBP8316—2048 X 8	TMS2516	—2048 X 8	TMS4060—4096 X 1	
SBP9818—2048 X 8	TMS2716	—2048 X 8	TMS4116—16,384 X 1	
	TMS2532	—4096 X 8	TMS4164—65,536 X 1	

*Character Generator—ASCII

**PROMS

STATIC RAMS

SN74S287— 256 X 4	TMS4008	—1024 X 8	TMS4043-2	— 256 X 4
SN74S471— 256 X 8	TMS4016	—2048 X 8	TMS4044	—4096 X 1
SN74S472— 512 X 8	TMS4033	—1024 X 1	TMS40L44	—4096 X 1
SN74S474— 512 X 8	TMS4034	—1024 X 1	TMS4045	—1024 X 4
SN74S476—1024 X 4	TMS4035	—1024 X 1	TMS40L45	—1024 X 4
SN74S478—1024 X 8 Δ	TMS4036-2	— 64 X 8	TMS4046	—4096 X 1
	TMS4039-2	— 256 X 4	TMS40L46	—4096 X 1
Δ Equivalent to SN74S2708	TMS4042-2	— 256 X 4	TMS4047	—1024 X 4
			TMS40L47	—1024 X 4

** Also available
in 54 series

Figure 2-3. Microcomputer Support Components

MICROCOMPUTER MODULES

TM990/100M	Microcomputer, 1-4K EPROM
TM990/101M	Microcomputer, 1-4K ROM, 1K-2K RAM
TM990/101M-10	Microcomputer, 1-4K ROM, 1K-2K RAM, Evaluation POWER BASIC®
TM990/180	Microcomputer, (8-Bit Data Bus), 1-2K ROM, 256-1K RAM
TM990/189	Microcomputer, University Microcomputer Module
TM990/201	Memory Expansion Module, 4K-16K ROM, 2K-8K RAM
TM990/206	Memory Expansion Module, 4K-8K RAM
TM990/301	Microterminal
TM990/302	Software Development Module
TM990/310	I/O Expansion Module
TM990/401*	TIBUG® Monitor in EPROM
TM990/402*	Line-by-Line Assembler in EPROM
TM990/450*	Evaluation POWER BASIC® —8K Bytes in EPROM
TM990/451*	Development POWER BASIC—12K Bytes in EPROM
TM990/452*	Development POWER BASIC Software Enhancement—4K Bytes in EPROM
TM990/501-521	Chassis, Cable and Power Supply Accessories

*FIRMWARE

Figure 2-4. TM990 Board Modules and Software Support

Software is provided in EPROM (firmware) to operate with the assembled microcomputer modules. It is provided on either “floppy” diskette or on disk pack for use with the minicomputers, and is distributed on magnetic tape for use on in-house computing equipment.

In addition to the development systems available directly from Texas Instruments, a Fortran-IV cross-support package with assembler and simulator is provided by TI for those desiring to use in-house computing equipment. GE, National-CSS and Tymeshare provide similar capabilities on a timeshared basis.

POWER BASIC and PASCAL software systems have just been introduced and will continue to be expanded in the future.

Hardware and software for development and production use is available in appropriate system sizes to support individual designers as well as large design teams.

▶ 2

- CS990/4
- A 990/4 Minicomputer with 4K words of RAM
 - Expanded memory controller with 4K words of RAM
 - 733 ASR ROM Loader
 - 733 ASR Data Terminal
 - Necessary chassis, power supply, and packaging

- FS990/4
- Model 990/4 Minicomputer with 48K bytes of parity memory in a 13-slot chassis with programmer panel and floppy disk loader/self-test ROM
 - Model 911 Video Display Terminal (1920 character) with dual port controller
 - Dual FD800 floppy disk drives
 - Attractive, office-style single-bay desk enclosure
 - Licensed TX990/TXDS Terminal Executive Development System Software with one-year software subscription service

- FS990/10
- Model 990/10 Minicomputer with 64K bytes of error-correcting memory and mapping in a 13-slot chassis with programmer panel and floppy disk loader/self-test ROM
 - Model 911 Video Display Terminal (1920 character) with dual port controller
 - Dual FD800 floppy disk drives
 - Attractive, office-style single-bay desk enclosure
 - Licensed TX990/TXDS Terminal Executive Development System Software with one-year software subscription service

- DS990/10
- Model 990/10 Minicomputer with mapping, 128K bytes of error-correcting memory in a 13-slot chassis with programmer panel and disk loader ROM
 - Model 911 Video Display Terminal (1920 character) with dual-port controller
 - Licensed copy of DX10 Operating System on compatible disk media, with one-year software subscription service
 - DS10 disk drive featuring 9.4M bytes of formatted mass storage, partitioned into one 4.7M-byte fixed disc and a 5440-type removable 4.7M-byte top-loading disk cartridge
- Options:
- One additional DS10 disk drive with 9.4M bytes of formatted mass storage, in deskmount, rackmount, or quietized pedestal version

Figure 2-5. 990 Minicomputers

PRODUCT DOCUMENTATION

9900 Family Systems Design and Data Book
 9900 Software Design Handbook
 TM990 System Design Handbook
 990 Computer Family Systems Handbook
 Product Data Manuals
 Product User's Guides
 Product Brochures
 Application Notes
 Application Sheets

SOFTWARE AND FIRMWARE

TM990/401	TIBUG Monitor in EPROM
TM990/402	Line-by-Line Assembler in EPROM
TMSW101MT	ANSI-Fortran Cross-Support Assembler, Simulator and ROM Utility
TM990/450	Evaluation POWER BASIC —8K Bytes in EPROM
TM990/451	Development POWER BASIC — 12K Bytes in EPROM
TM990/452	Development POWER BASIC Software Enhancement Package — 4K Bytes in EPROM
TMSW201F/D	Configurable POWER BASIC in FS990 Diskette
TMSW301F/D	TIPMX — TI PASCAL Executive Components Library

SOFTWARE DEVELOPMENT

SUPPORT SOFTWARE

TM990/302	Software Development Module	Edit, Assembler, Load, Debug, PROM Programming Assembler, Debug Monitor, Trial-in-System Emulator, PROM Programmer
TM990/40DS	Software Development system for TMS9940 Microcomputer	
CS990/4	Single User Software Development System (Cassette Based), uses PX990 software.	Text Editor, Assembler, Linking Loader, Debug Monitor, PROM Programmer
FS990/4	Software Development system (Floppy Disk)	Source Editor, Assembler, Link Editor, PROM Programmer
FS990/10	Software Development System (Floppy Disk)	Same as 990/4, expandable to DS System
DS990/10	Disk Based 990/10 with Macro Assembler	Source Editor, Link Editor, Debug, Librarian, and High-Level Language such as FORTRAN, BASIC, PASCAL, and COBOL

MICROPROCESSOR PROTOTYPING LAB FOR DESIGN AND DEVELOPMENT

AMPL FS990 with video display and dual floppy diskettes includes TX990/TXDS system software — Text Editor, Assembler, and Link Utility — and has an in-circuit Emulator Module and a Logic-State Trace Module for proposed system emulation and analysis.

TIMESHARE SYSTEMS

GE, NCSS, Tymeshare	Assembler, Simulator, ROM Utilities
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Figure 2-6. The 9900 Family Software and Development Systems

TYPICAL APPLICATIONS

The range of applications for microprocessors and microcomputers expands each day; *Figure 2-7* provides a broad scope of the applications extending from those that can be satisfied with single-chip microcomputers to those requiring high performance multichip systems. The market tends to be characterized by lower performance, high volume single-chip systems, and higher performance, low volume multichip systems.

As shown in *Figure 2-7*, the spectrum of applications is satisfied throughout by 9900 Family members. The single-chip 16-bit microcomputer, the TMS 9940, is used where there is large volume, because it has the lowest cost, yet achieves outstanding performance. At the other end are the system with the 16-bit TMS 9900 and SBP 9900A CPUs, the specially designed family peripherals, and add-on memory. For maximum system performance, the bit slice SN74S481 units are available. For in-between performance limits there are the 16-bit CPUs using 8-bit data buses. The TMS 9980A/81 has lower cost, and the TMS 9985 will accommodate larger memory for extended applications. Both processors use the more economical 40-pin package. Applications in the low and medium performance range include simple instruments, computer peripherals, cash registers and controls for manufacturing.

At the higher performance end, a myriad of products that are emulating many computer-like functions — data terminals, point-of-sale terminals, data acquisition systems, process control systems, military systems — are all gaining performance at lower cost by using microprocessor multichip systems.

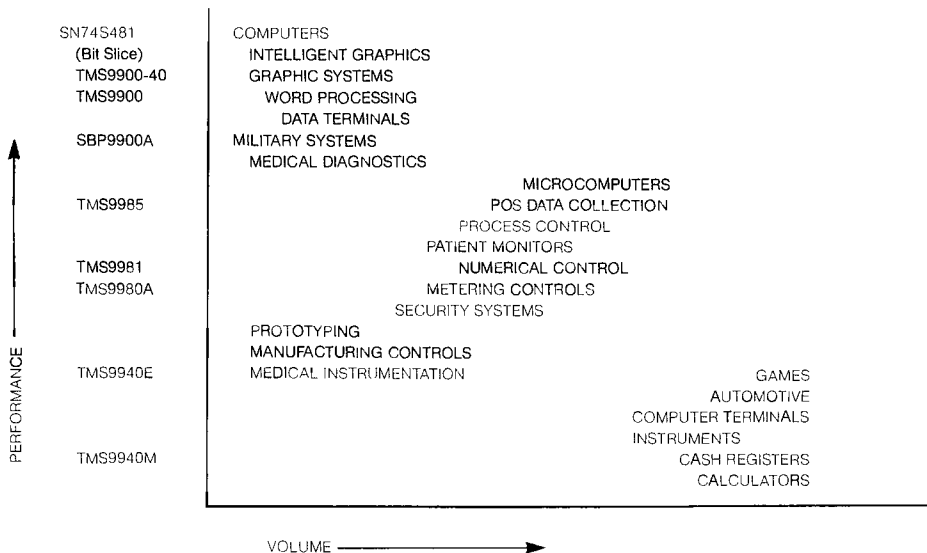


Figure 2-7. Application Spectrum

Figure 2-8 details further the applications for single-chip and multiple-chip systems.

SINGLE-CHIP MICROCOMPUTER	MULTIPLE-CHIP SYSTEMS	
Gas Pump Control	Video Controllers	CPU's-Microcomputer
Alarm Systems	Telephone Switching	Computer Peripherals
Paging Systems	Word Processing Equipment	Intelligent Terminals
Sorters	Manufacturing Material Handlers	Tape Drive Controls
Vending Machines	Electronic Musical Instruments	Graphic Terminals
Microwave Ovens	Small Business/Financial Systems	Communications Network
Appliance Control	Factory Automation	Communications Processing
Power Tools	Instrumentation	Data Concentration
Utility Meter Monitoring	Data Acquisition	Input Terminals
Environmental Controls	Machine Controls	General Purpose Terminals
Automotive	Medical Equipment	
Games	Security Systems	
Cryptography	Machine Tool Controls	
Process Controls		
Navigation Equipment		
Metering Controls		

Figure 2-8. Applications

HARDWARE SELECTION

To reduce the range of detail which must be considered in a given system design, it is often possible to make a definite choice between the three hardware design levels; designing with individual components, designing with prefabricated modules, and designing with minicomputer subsystems. The criteria upon which this choice is based include the number of units to be manufactured per design, complexity of design, performance requirements, special feature requirements, microprocessor system design expertise available, and the importance placed on product introduction — the time to the market place. General tendencies of these decisions are known although the particular choice may be skewed by other considerations. Here are a number of examples.

In terms of production volume, users tend to incorporate minicomputers in their designs up to a volume of 50 to 100 identical systems per year. They tend to use prefabricated modules if the volume is below 500 to 2000 systems per year, and for higher volume, they tend to develop from the component level right from the start. Simple systems may not be able to stand the cost of a minicomputer at any volume, while even at much higher volumes, performance requirements may force the utilization of a disk-based minicomputer. When system specifications require special features, this often forces the use of modules even at low volumes. However, the need for maintenance capability may force the use of minicomputers or prefabricated modules for system construction at extremely large volumes. A firm with expert microprocessor design teams would tend to maximize its value-added by designing from the component level, while a firm without hardware designers would look for completely prefabricated systems.

Finally, product introduction priorities often call for a compromise approach because of an urgent need to get a product to market ahead of competition. It is often ideal to enter the market with prefabricated systems and switch to in-house fabrication as the system is accepted and sales volume builds.

THE COMPONENT ROUTE: CPU

In the beginning your product selection decisions are tied entirely to the central processor. A very real danger at this point is choosing a processor which is not optimum for the design. Either the cost will be greater than desired, or the processor will not quite meet the required performance. In the TMS9900 Family, each processor is uniquely tuned to its applications environment while maintaining a common architecture, input/output system and instruction set. This commonality allows a simple move up or down the performance scale with a minimum of redesign (See Figure 2-9).

The single packaged CPUs divide into microprocessors and a microcomputer. The TMS 9940 microcomputer is available either with EPROM or with mask programmable ROM.

<i>Microprocessors</i>		<i>Microcomputer</i>
TMS9900	TMS9980A/81	TMS9940 E/M
TMS9900-40	TMS9985	
SBP9900A		

The basic architecture of each is shown in Figure 2-10.

CRITERIA	SYSTEM CHOICE	FAMILY PRODUCTS USED
HIGHEST PERFORMANCE	MULTIPACKAGE	<ol style="list-style-type: none"> 1. TMS9900, SBP9900A 2. Microcomputer peripherals for I/O 3. TIM9904 for clock 4. ROM, EPROM 5. RAM
TRADEOFF FOR BEST COST AT PERFORMANCE REQUIRED	A. MINIMUM PACKAGES	<ol style="list-style-type: none"> 1. TMS9980A/81 (with clock) 2. Microcomputer peripherals for I/O 3. Combined ROM & RAM
	B. MINIMUM PACKAGES	<ol style="list-style-type: none"> 1. TMS9985 (with clock and RAM) 2. Microcomputer peripherals for I/O 3. ROM
LOWEST COST	SINGLE PACKAGE	<ol style="list-style-type: none"> 1. TMS9940 Microcomputer with on board I/O, Clock, ROM & RAM, Timer

Figure 2-9. Cost/Performance Trade-off

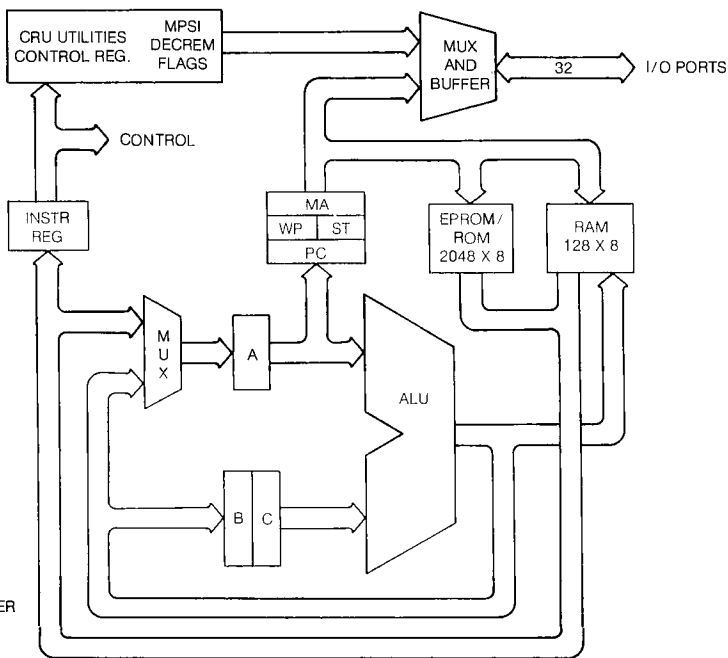
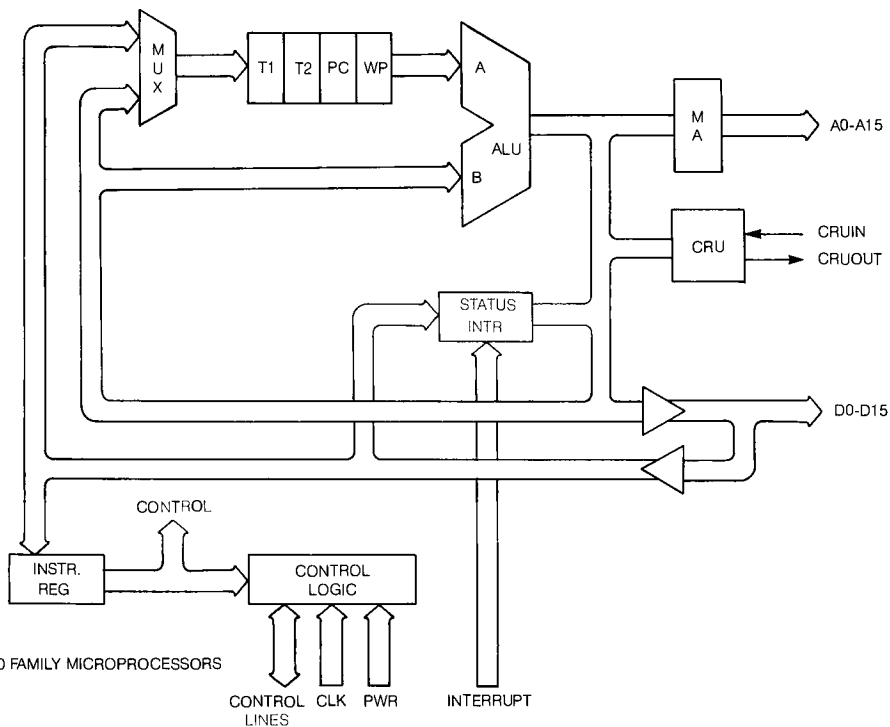


Figure 2-10. Basic Architecture of 9900 Family

CPU Selection

Selecting a CPU for an application requires a study of the CPU characteristics to see which one fits best. *Figure 2-11* provides key characteristics of the 9900 Family CPUs as well as a bit-slice version (SN54/74S481) for the ultimate in performance.

DEVICE	SN54S481 SN74S481 Note 1	SBP9900A	TMS9900/ TMS9900-40	TMS9980A/ TMS9981	TMS9985	TMS9940E/M
Number of bytes addressable	65K	65K	65K	16K	65K 256 on chip	2K EPROM/128 RAM 2K 128 RAM/128 RAM
Number of Interrupts	16	16	16	5	5	4
Number of Pins	48/chip	64	64	40	40	40
Power Supply Requirements	+5	Resistor Programmable Note 2	+12, ±5	+12, ±5	+5	+5
Technology	Schottky TTL	PL	NMOS	NMOS	NMOS	NMOS
Environmental (Temperature, °C)	-55 to 125	-55 to 125	0 to 70	0 to 70	0 to 70	0 to 70
Clock Rate	10MHz	3MHz	3.3MHz/4MHz	10MHz	5MHz	5MHz
Relative Thruput	6	0.9	1.0/1.3	0.6	0.65-0.8 Note 3	1.2
Number of Address Bus Lines	15	15	15	14	16	Note 4
Number of Data Bus Lines	16	16	16	8	8	Note 4
Clock	SN54S124	SN54LS124	TIM9904	On Chip	On Chip	On Chip

Note 1 : Based on four slices microcoded to duplicate TMS9900.

Note 2: Voltage for the SBP9900A is 1.5 to 30 volts with a series resistor.

Note 3: Relative thruput is 0.65 with off-chip RAM and 0.8 with on-chip RAM.

Note 4: No external memory or data bus. 32 general purpose I/O pins 10 of which provide 256 bit CRU I/O expansion if desired.

Figure 2-11. Key Characteristics of 9900 Family CPUs

Figure 2-12 provides, in a “quick look” format, four specifications of the family members that are usually important to all applications — the directly addressable memory, the data bus length, the operating temperature, and the package size.

Figure 2-13 plots the relative thruput of the 9900 Family microprocessors and microcomputers. The thruput, estimated by calculating execution times for a given benchmark program, is plotted relative to the performance of the TMS9900. 30% more thruput is obtained using the TMS9900-40. The thruput of the SBP9900A is 90% of the TMS9900. Both of these processors operate with a full 16-bit data bus and are in 64-pin packages. As mentioned previously, ultimate performance is obtained by using a bit-slice microprocessor. A relative thruput of six is shown for four SN54/74S481 bit-slice packages microcoded to duplicate a TMS9900.

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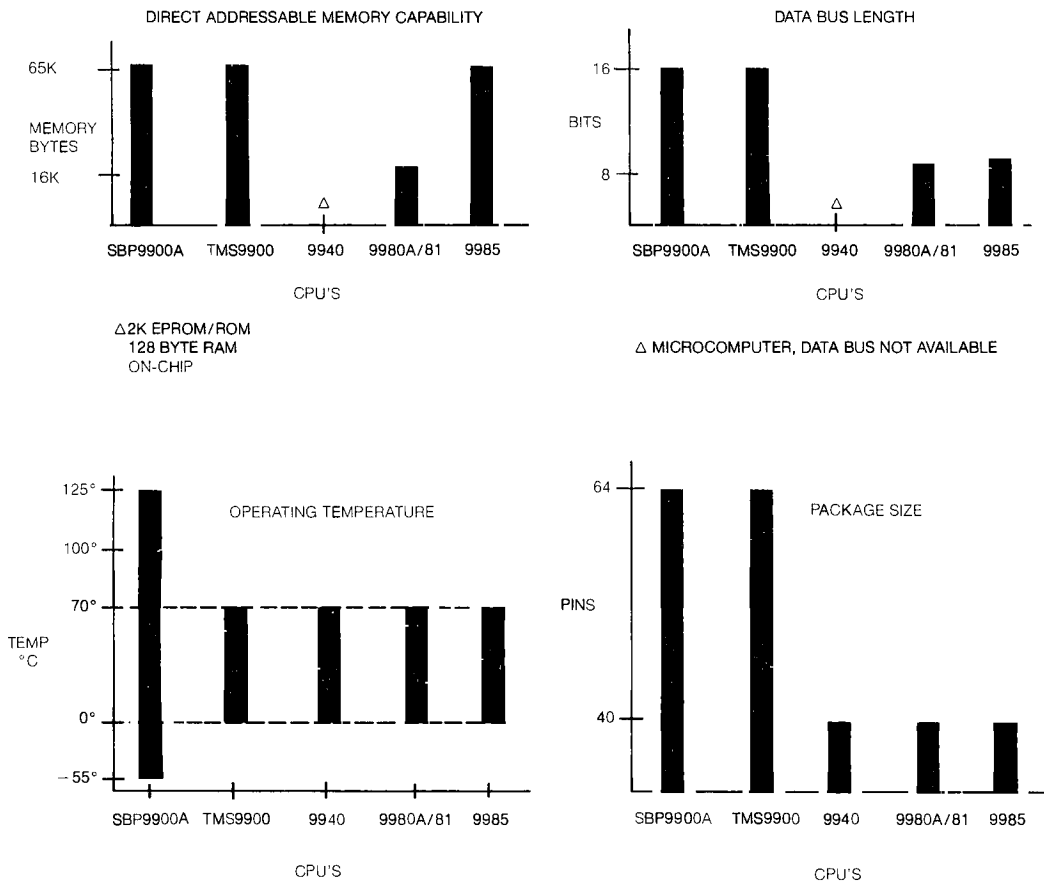


Figure 2-12: “Quick Look” at 9900 Family CPU’s

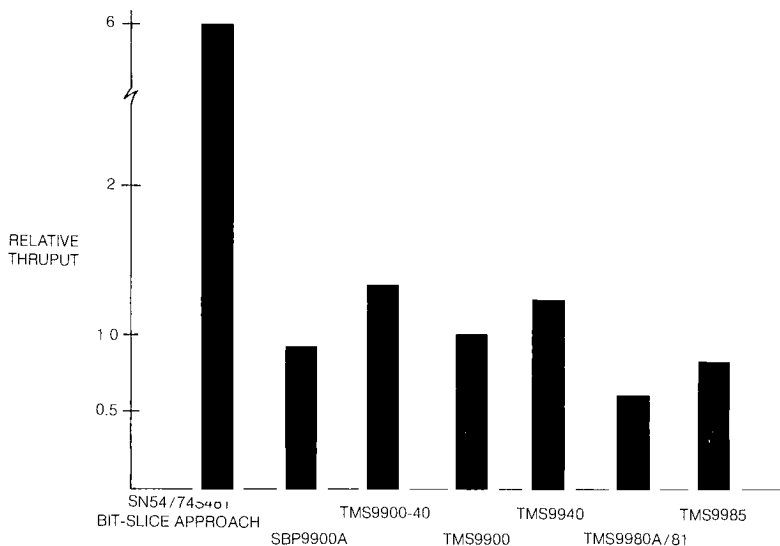


Figure 2-13. Thruput of 9900 Family CPU'S

Cost reduction can be realized via 40-pin packaging. This is accomplished by changing the external operating configuration to an 8-bit format even though the internal processor is a 16-bit processor. This causes a reduction in thruput — the thruput of the 9980A/81 and 9985 is reduced to 60% to 80% of the TMS9900 — because a byte organized memory is required and the number of memory accesses will obviously be increased. The advantage, of course, is that family software can be used even though the 8-bit configuration is used. Note that the 9940 microcomputer thruput is 20% *greater* than the TMS9900. Excellent performance is obtained from this single-chip microcomputer.

The 9980A/81 is designed for the lowest system cost for full family performance while the 9985 spans the link between microprocessor and microcomputer by offering RAM memory on board.

Flexible I/O

The TMS9900 provides non-multiplexed parallel I/O and memory control for maximum performance when needed, with full 16-bit address and data bus. It also has a separate serial bus to allow use of minimum cost, maximum functionality peripherals for relatively slow I/O processes which will tolerate the reduced speed. This is the Communications Register Unit, CRU.

Family Members Fitted to the Application

The TMS9980A/81 and the TMS9985 multiplex the data bus for reduced cost and package size at some sacrifice in performance. The TMS9940 is the least expensive approach for those applications which will tolerate the limitations of a single-chip. It provides full computer capabilities, albeit of a limited range, on a single integrated circuit. By not taking the address and data bus off-chip, buffer time delays are eliminated resulting in higher performance within a limited memory range (2K EPROM/ROM, 128 bytes RAM). For those applications requiring better temperature or reliability performance than that available from NMOS processors, the SBP9900A provides the same sophisticated processor functions as the TMS9900 over military and industrial temperature and specification ranges.

Interrupt Flexibility

The 9900 Family provides fully prioritized, vectored interrupts as well as software vectored interrupts for maximum flexibility.

ADVANTAGES OF 9900 FAMILY CPUs

True Compatibility

The greatest advantage of using the 9900 Family as mentioned earlier, is the fact that it is a truly compatible family. Many so-called families of CPUs are not truly compatible in instruction set, in I/O interfacing, or in architecture. The 9900 Family attains compatibility in all three areas. It is difficult and expensive to move from the use of one microcomputer family to the use of another. Of equal importance, in non-compatible families, it is often just as expensive to move from one member to another. When faced with such a move, serious consideration should be given the 9900 family, because doing so can eliminate most of the trauma of future moves, and quite possibly ease the present one.

Lower Costs

As seen in Chapter 1, while system costs are dropping at a 15% to 20% yearly rate, software costs are actually rising. Thus, a family that provides the same and more capabilities with less programming saves software costs. The sophisticated memory-to-memory instruction set of the 9900 Family eases assembly language programming, at the same time reducing the memory storage requirement and increasing execution speed.

Instruction Set

Instruction sets are inherently difficult to compare. *Figure 2-14* is a relatively simple way. It gives three numbers for each of three representative microprocessor families. The second number is the number of instructions used by manufacturers when advertising their product. In many cases it has little to do with the power of the instruction set. The first number is the number of distinct functions included in the instruction set. It represents to a certain extent the uniqueness of the instruction set. In the 8080 and 6800 families, instructions which take care of redundant actions solved automatically by the 9900 Family are not included. The third number represents combinations. Many advertised instructions are obtained by giving a separate name to particular combinations of the basic functions and addressing modes. Many of these are possible. The last set of numbers shows the result of taking the third number to its extreme and listing all possible combinations for each of the families. 62,235 are possible for the 9900 Family. The number of possible combinations is derived from the fact that certain instructions leave several bits unspecified to allow for a variety of addressing modes. In the 9900, 12 instructions (Add, Subtract, etc.) leave 12 bits unspecified, so there are 4096 (2^{12}) variations of each, times 12, or 49,152 combinations. Eight-bit instruction sets simply do not allow this degree of flexibility.

INSTRUCTIONS	PROCESSOR		
	8080	6800	9900
DISTINCT	27	26	36
ADVERTISED	78	72	69
COMBINATIONS	237	169	62,235

Figure 2-14. Instruction Set Comparison

Memory-to-Memory Architecture

Memory-to-memory architecture means high speed context switching in interrupt processing and in subroutine processing. All processors must save the contents of the CPU registers as a prerequisite to processing an interrupt service routine. The register contents to be saved include the PC (program counter), ST (Status register), and one or more general registers. For the 9900, the registers to be saved are *only* the PC, ST and WP (workspace pointer).

THE COMPONENT ROUTE: PERIPHERALS

Microcomputer component peripherals perform functions that assist the CPU in a microprocessor or microcomputer system. Data communications through serial data links in a synchronous or asynchronous mode; parallel input and output interfaces for general purpose I/O, instrument communications, direct memory access or mass storage control; and display control and memory expansion and control are some of the present peripheral functions provided as shown below.

2

FAMILY UNITS—INTERFACING TECHNIQUES

Serial I/O for Data Communications

Asynchronous Communications Controller	TMS9902
4 MHz Version	TMS9902-40
Synchronous Communications Controller	TMS9903

Parallel I/O

General Purpose

Programmable Systems Interface	TMS9901
4 MHz Version	TMS 9901-40
I/O Expander	SBP9960
Interrupt—Controller/Timer	SBP9961

Instrument Communications

General Purpose Interface Bus Adapter	TMS9914
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Direct Memory Access

Direct Memory Access Controller	TMS9911
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Mass Storage

Floppy Disk Controller	TMS9909
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CRT Display (Memory Mapped I/O)

Video Timer/Controller	TMS9927 ✓
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Memory

Combination ROM/RAM Memory	TMS9932
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Memory Control

Dynamic RAM Controller Chip Set

Refresh Timing Controller	TIM9915A
Memory Timing Controller	TIM9915B
Multiplexer/Latch	TIM9915C

FAMILY UNITS—SUPPORT LOGIC

Four-Phase Clock Driver	TIM9904
8 to 1 Multiplexer	TIM9905
8-Bit Latch	TIM9906
8 to 3 Priority Encoder	TIM9907
8 to 3 Priority Encoder W/Three State Outputs	TIM9908

Significant progress has been made in implementing these important functions in high-functional-density designs for the 9900 Family. This integration will continue in the future. It provides cost-effective package substitutions for multiple standard TTL units. The result is reduced assembly costs and materials, increased reliability, and shorter time from design to production.

2 As the key features of the microcomputer component peripherals are reviewed, note these points: (1) Many of the peripherals units are as complex or even more complex than the CPUs they support; (2) Many of the peripheral units are designed to be *programmable* providing outstanding flexibility to vary their use in system applications. Such design trends reinforce the systems concept of the future—that standard hardware will be used but varied in use by software; (3) Family units will drive two TTL loads, allowing direct interface to low-power Schottky, standard TTL, and even standard Schottky circuits, eliminating the need for many special purpose peripherals which do little else than provide this interface.

Interface Techniques

A computer must be controlled by a person or another machine to be useful. It must be programmed to accept inputs, process data, and give results as outputs. It will do only what it is programmed to do (barring malfunction). Output results must be acted upon otherwise the computer manipulations are worthless. Peripheral components form the required systematic interface between the computer and the outside world and range in functional capability from the general purpose to highly specialized units.

The interface of a microcomputer or microprocessor system to external inputs and outputs is by serial or parallel data lines. Two parallel and two serial techniques are used. The parallel techniques include direct memory access and CPU controlled I/O. The serial techniques include asynchronous and synchronous serial I/O. A final technique called interrupt is used to alert the processor of a change in external conditions.

Serial I/O for Data Communications

Serial I/O for data communications is handled through the TMS9902 and TMS9903. The TMS9902 and TMS9902-40 are for asynchronous serial data that is established around the RS232C protocol and the TMS9903 is for synchronous data, designed for any high-speed communications protocol. CPU control of these devices, as show in *Figure 2-15* via the Communications Register Unit, allows their construction in small, plug-compatible packages.

Parallel I/O

GENERAL PURPOSE

General purpose parallel I/O and interrupt control along with an on-chip timer are provided by the TMS9901 and TMS9901-40, as shown in *Figure 2-15*. The same functions are served in I²L for extended temperature range operation by the SBP9960 and SBP9961.

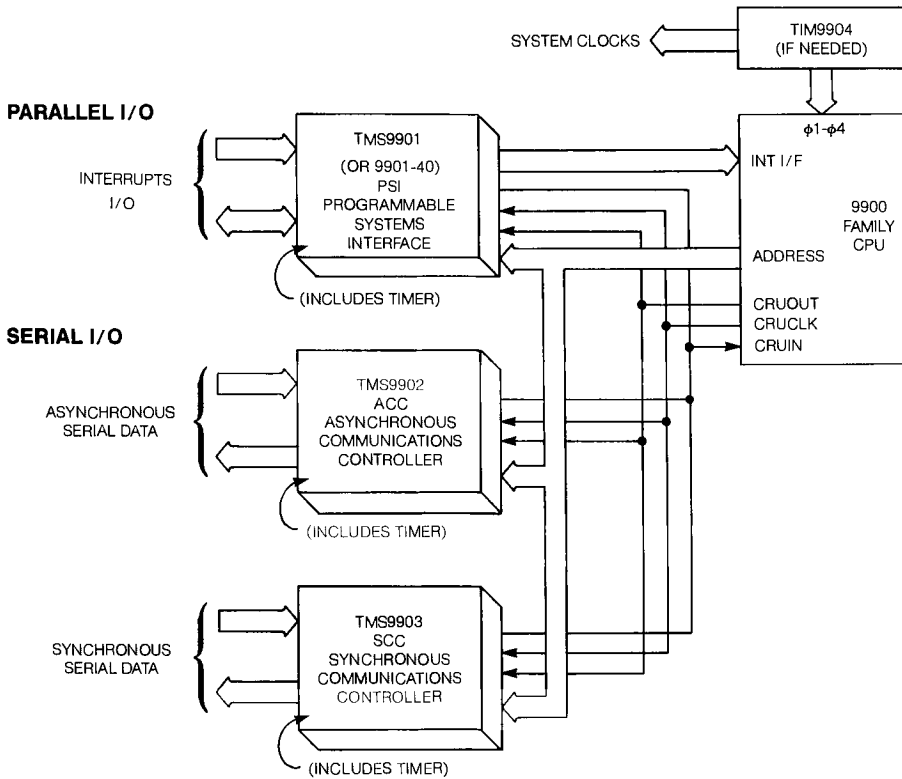


Figure 2-15. Microcomputer Component Peripherals for I/O Interface

A significant advantage of the 9900/9901 parallel I/O interface through the CRU is the ability to transfer fields of from 1 to 16 bits of data as inputs or outputs under the command of one instruction and to modify this structure from instruction to instruction. Additionally, use of the CRU allows implementation of multiple functions in the TMS9901.

MEMORY-MAPPED

Since the CRU is essentially a time-division multiplexed serial port, speed critical applications may require a faster parallel technique. Memory-mapping, the treatment of a parallel I/O port as if it were a memory location, provides this technique. With the memory-to-memory architecture of the 9900 Family, direct manipulation of such an I/O port is practical. The dual-TTL drive of the 9900 Family allows economical construction of memory-mapped I/O ports using standard TTL or LS (Low-Power Schottky) components.

GPIB—GENERAL PURPOSE INTERFACE BUS

In 1975 the IEEE defined a very precise electrical and mechanical protocol designated the IEEE 488 Interface Bus, or commonly known as a General Purpose Interface Bus (GPIB). This protocol allows direct connection of instruments and processors supplied by various manufacturers. The TMS9914 General Purpose Interface Bus Adapter either directly, or under software control, adapts all the capabilities of the GPIB to a microprocessor bus including talker, listener, controller and control passer. This is a general purpose component and will work quite well with any microprocessor, although it is complemented by the speed and power of the 9900 Family.

DMA—DIRECT MEMORY ACCESS

Many I/O devices can be made more effective if transfer rates can be increased beyond the 8 microseconds required for a typical memory-mapped transfer. The GPIB mentioned above, for instance, allows data transfers at rates up to a million bytes per second. The TMS9911 Direct Memory Access Controller allows low cost implementation of two such super high speed ports. The TMS9911 itself is controlled by the CPU via the CRU bus, until one of the DMA channels takes control long enough to process a DMA transfer (either single or block) between I/O port and memory.

FLOPPY DISK

For those applications requiring more storage space than is convenient or economical in a microcomputer, a mass storage device is needed. Floppy disk units provide the benefits of fast access, reliable mass storage using a portable, easily stored media. Interfacing these units to microprocessors is greatly simplified by the TMS9909 Floppy Disk Controller. This device will control up to four floppy disk units using standard or minifloppies, single, double, or triple density, hard or soft sectors. It is also capable of full IBM compatibility (including double-sided, double density at the *same* time). This is a general purpose component and will work quite well with any microprocessor. It is a memory-mapped device and will also interface easily to a DMA controller such as the TMS9911. The TMS9909 can be programmed for:

1. Data encoding formats
2. Number and type of diskette drives
3. Stepper motor control rates
4. Number of sectors and tracks

It can perform the following functions:

1. Step to any track on the diskette
2. Format tracks (set initial conditions on diskette)
3. Read and write diskette data
4. Send status to the host system

CRT CONTROL

The TMS9927 video timer/controller is a memory-mapped device which contains all of the logic necessary to generate all the timing signals for display of video data on CRT monitors, standard or not, and interlaced or not.

This video timer/controller has nine 8-bit registers used for programming; seven for horizontal and vertical formatting and two for the cursor character and address. All the functions for generating the timing signals for video data display are programmable:

1. Characters per row
2. Data rows per frame
3. Raster scans per data row
4. Raster scans per frame

All timing functions are implemented on the chip except the dot generation and dot counting which operate at video frequency. A character generator and shift register are used to shift out video data. The control registers can be loaded by the microprocessor or from PROM. This is a general purpose part for use with any microprocessor.

MEMORY

Contained in the microcomputer component peripherals is a unit for memory expansion, the TMS9932, a combination ROM/RAM memory unit with 1920 bytes of ROM and 128 bytes of RAM. It contains the same key features that characterize the 9900 Family support memory.

MEMORY CONTROL

The TIM9915 chip set consists of 3 packages, a 16-pin Refresh Timing Controller (TIM9915A), a 16-pin Memory Timing Control (TIM9915B), and a 28-pin Multiplexer/Latch with tri-state outputs (TIM9915C). *This chip set becomes the complete packaged set for 4K to 64K of dynamic RAM memory, and provides all the timing and control signals necessary to interface dynamic RAM memory and make it appear as static RAM.*

Clock and Support Logic

Four-Phase Clock Generator/Driver

Microprocessor and microcomputer systems require clock generators and drivers for the timing control of the system. The TMS9904 is such a unit. An oscillator which can be crystal or inductance controlled provides the basic timing source. Four high-level clock phases provide the 9900 microprocessor timing. Four additional TTL-level clocks can be used to time memory or other control functions in a 9900 system.

Support Logic

Common TTL MSI peripherals included in the 9900 Family of microcomputer components are:

TIM9905	8 to 1 Multiplexer
TIM9906	8-Bit Latch
TIM9907	8 to 3 Priority Encoder
TIM9908	8 to 3 Priority Encoder w/Tri-State Outputs

The reason, of course, is that they are standard units for accomplishing the following tasks:

1. Parallel-to-Serial Conversion
2. Multiplexing from N-lines to one line
3. Providing multiple data selectors
4. Providing bus interface from multiple sources
5. Encoding 10 line decimal to 4 line BCD
6. Encoding 8 lines to 3 lines

All units are fabricated using standard low-power Schottky TTL technology in 16-pin packages. They have tri-state output drivers to interface directly with a system bus and are fully compatible with all TTL interfaces.

Cost Effectiveness of NMOS LSI Peripherals

Figure 2-16 clearly demonstrates the cost effectiveness of the specially designed CRU microcomputer component peripherals. The replacement of large numbers of less complex packages provides a significant reduction in cost due to simplified design, layout, assembly and testing, besides the reduced material costs.

In addition, there are major contributions to improving the reliability of the system just by reducing the number of packages and the associated solder connections and assembly connections external to the IC.

FUNCTION	UNIT USED	SSI AND MSI PACKAGES REPLACED
INTERRUPTS AND I/O	TMS9901	23
ASYNCHRONOUS SERIAL COMMUNICATIONS	TMS9902	45
SYNCHRONOUS SERIAL COMMUNICATIONS	TMS9903	100

Figure 2-16. System Package Reduction Using Microcomputer Component Peripherals

CRU Interface

In the features for the 9900 Family, the Communications Register Unit interface provides:

1. The most cost effective I/O for low and medium speed peripherals via the instruction driven serial data link.
2. Completely separate address space.
3. A choice of transferring fields of 1 to 16 bits per instruction.

The CRU serial data link is an effective mechanism for operation-per-instruction I/O. The CRU interface is simpler and therefore less expensive than memory-mapped I/O. In applications where there are many I/O transfers of one or two bits, the CRU serial data link provides execution times that are better than for memory-mapped I/O, which always transfers 8 or 16 bits at a time.

One way of demonstrating the cost effectiveness of the CRU is shown in *Figure 2-17*. Package pins per function are less using the CRU interface and the 9900 Family units. Thus, costs are saved over memory-mapping in implementing the example I/O functions shown.

FUNCTION	CRU PINS	MEMORY MAPPED PINS
8-Bit Output	16 (TIM9906)	24
UART	18 (TMS9902)	24-40
USRT	20 (TMS9903)	24-40

Figure 2-17. CRU vs Memory Mapped I/O – Package Pins Required Per Function

THE COMPONENT ROUTE: MEMORY

Semiconductor memory is the most natural storage media to add to a 9900 system. It has fast access times, an interface that is completely compatible with the microprocessor or microcomputer, and high-density storage per package. Texas Instruments offers a broad spectrum of storage media products in support of the 9900 Family as shown in *Figure 2-18*, *2-19* and *2-20*. These products encompass dynamic and static random access memory, mask programmable read-only memory, fused-link programmable read-only memory, and erasable programmable read-only memory.

WORDS	BITS PER WORD				
	1	2	4	8	
16			TMS 4S188 SN54/74S188		
32				7488A SN54/74188A SN54/74S188 74S288	
64	0 SI			036	
128					
256	14 SN54/74S201 SN54/74S301		TMS 4042, TMS 4043 SN74S208 ROMs SN54/74187	74S271 SN54/74S371 PROMs SN54/74S470 SN54/74S471	
512				ROMs SN54/74S477 SN54/74S478 S*	
1024	103 TMS 4033 TMS 4034 TMS 4035 TMS 4062 TMS 4063 SN74S309	2048 SN74S, LS314 SN74LS315	RAMs TMS 4045 TMS 40L45 TMS 4047	PROMs SN74S476 SN74S477	008 EPROMs TMS 2508 700 710 PROMs SN74S478 SN74S2708
2048			54	016 E Ti TMS 2710	
4096	RAMs TMS 4027 TMS 4044 TMS 4046 TMS 408U TMS 40L46		800	1732	
8192					
16384	RAM TMS 4116				
32768					
65536	164 064				

Figure 2-18. Matrix of Memory Products

DYNAMIC RAMS

TYPE	ORGAN.	TECH	PINS	ACCESS TIME-ns	*PKG. P ₀ -mW	POWER	TEMP
TMS4027	4096 X 1	NMOS	16	150-200	460	+5V, -5V, +12V	0°C-70°C
TMS4050	4096 X 1	NMOS	18	200-300	420	+5V, -5V, +12V	0°C-70°C
TMS4051	4096 X 1	NMOS	18	250-300	460	+5V, -5V, +12V	0°C-70°C
TMS4060	4096 X 1	NMOS	22	150-300	400	+5V, -5V, +12V	0°C-70°C
TMS4116	16,384 X 1	NMOS	16	100-200	462	+5V, -5V, +12V	0°C-70°C
TMS4164	65,536 X 1	NMOS	16	100-150	200	+5V	0°C-70°C

*MAXIMUM

STATIC RAMS

TYPE	ORGAN.	TECH.	PINS	ACCESS TIME-ns	*PKG. P ₀ -mW	POWER	TEMP.
TMS4008	1024 X 8	NMOS	24	150-450	450	+5V	0°C-70°C
TMS4016	2048 X 8	NMOS	24	150-450	495	+5V	0°C-70°C
TMS4033	1024 X 1	NMOS	16	450	368	+5V	0°C-70°C
TMS4034, 35	1024 X 1	NMOS	16	650-1000	368	+5V	0°C-70°C
TMS4036-2	64 X 8	NMOS	20	450-1000	450	+5V	0°C-70°C
TMS4039-2	256 X 4	NMOS	22	450-1000	368	+5V	0°C-70°C
TMS4042-2	256 X 4	NMOS	18	450-1000	368	+5V	0°C-70°C
TMS4043-2	256 X 4	NMOS	16	450-1000	368	+5V	0°C-70°C
TMS4044	4096 X 1	NMOS	18	150-450	440	+5V	0°C-70°C
TMS40L44	4096 X 1	NMOS	18	200-450	275	+5V	0°C-70°C
TMS4045	1024 X 4	NMOS	18	200-450	495	+5V	0°C-70°C
TMS40L45	1024 X 4	NMOS	18	200-450	300	+5V	0°C-70°C
TMS4046	4096 X 1	NMOS	20	150-450	440	+5V	0°C-70°C
TMS40L46	4096 X 1	NMOS	20	200-450	275	+5V	0°C-70°C
TMS4047	1024 X 4	NMOS	20	150-450	495	+5V	0°C-70°C
TMS40L47	1024 X 4	NMOS	20	200-450	300	+5V	0°C-70°C

*MAXIMUM

Figure 2-19. Dynamic and Static RAM in Support of 9900 Family

READ ONLY MEMORIES

ROM

TYPE	ORGAN.	TECH.	PINS	ACCESS TIME-ns	PKG. Po-mW	POWER	TEMP.
TMS4700	1024 X 8	NMOS	24	450	*580	+5V, -5V, +12V	0°C-70°C
△TMS4710	1024 X 8	NMOS	24	450	*580	+5V, -5V, +12V	0°C-70°C
TMS4732	4096 X 8	NMOS	24	450	*788	+5V	0°C-70°C
SBP8316	2048 X 8	ℓL	24	650	500	+5V (1.5V-30V)	-55°C to +125°C 0°C-70°C
SBP9818	2048 X 8	ℓL	24	200	500	500 MA	-55°C to +125°C

△Character Generator

*MAXIMUM

PROMS

TYPE	ORGAN.	TECH.	PINS	ACCESS TIME-ns	PKG. Po-mW	POWER	TEMP.
SN54/74S287	256 X 4	TTL(s)	16	42	*708	+5V	SN54: 0°C-70°C
SN54/74S471	256 X 8	TTL(s)	20	50	*814	+5V	SN74: -55°C to +125°C
SN54/74S472	512 X 8	TTL(s)	20	55	*814	+5V	"
SN54/74S474	512 X 8	TTL(s)	24	55	*814	+5V	"
SN54/74S476	1024 X 4	TTL(s)	18	35	*735	+5V	"
SN54/74S478	1024 X 8	TTL(s)	24	45	600	+5V	"
SN54/74S2708	1024 X 8	TTL(s)	24	45	600	+5V	"

*MAXIMUM

EPROMS

TYPE	ORGAN.	TECH.	PIN	ACCESS TIME-ns	*PKG. Po-mW	POWER	TEMP.
TMS2508	1024 X 8	NMOS	24	350	500	+5V	0°C-70°C
TMS2708	1024 X 8	NMOS	24	350-450	800	+5V, -5V, +12V	0°C-70°C
TMS27L08	1024 X 8	NMOS	24	450	475	+5V, -5V, +12V	0°C-70°C
TMS2516	2048 X 8	NMOS	24	450	525	+5V	0°C-70°C
TMS2716	2048 X 8	NMOS	24	450	595	+5V, -5V, +12V	0°C-70°C
TMS2532	4096 X 8	NMOS	24	450	840	+5V	0°C-70°C

*MAXIMUM

Figure 2-20. Read Only Memory in Support of 9900 Family

Standard Memory and Compatibility

A very important characteristic of the 9900 Family is that it uses standard semiconductor memory not memory that depends on a custom multiplexed or latched bus. The full range of MOS, TTL, I²L and ECL memories are shown in *Figure 2-18*. Many of these units that support the 9900 Family are pin-compatible for ease in conversion from development systems to production systems.

As an example, during development, package flexibility is provided. Initially, a static RAM is used; then EPROM's can be substituted as the system design stabilizes, and when the system is proven and in volume production, mask ROM can be substituted.



Here is an example of the socket compatibility:

<u>MEMORY SIZE</u>	<u>SRAM</u>	<u>EPROM</u>	<u>PROM</u>	<u>ROM</u>
1K × 8	4008	2508	SN74S2708/478	
1K × 8		2708	SN74S2708/478	4700
2K × 8	4016	2516		SBP8316, SBP9818
4K × 8		2532		4732

(All of these devices can fit a single socket.)

Even if the memory units are not completely compatible, due to power supplies or control pins, simple jumpers can be used to maintain socket compatibility.

Read-Only Memory: Costs and Flexibility

Figure 2-21 shows the characteristics of read-only memories and their cost per bit vs. design flexibility. Mask programmable read-only memory is lowest cost per bit but also has no flexibility. It is used for high volume production after a design is proved to be correct and no changes are expected. PROMs have excellent performance and have more flexibility because programming is done after they are manufactured. However, once programmed they cannot be changed. PROMs cost somewhat more than ROMs because they use more real estate. EPROM has much more flexibility because design changes are done quickly and because it is reuseable, but EPROM costs more to manufacture than ROM or PROM because it is eraseable. EAROM is also indicated in *Figure 2-21*. This is really "read mostly" memory, because it can be erased in a relatively short period of time (microseconds), but once programmed again, it acts like fixed storage. EAROMs as a practical product are still a bit in the future. The flexibility of EPROMs is well worth the added cost. This is especially true when used as a prototyping tool.

A. READ-ONLY MEMORY CHARACTERISTICS

	ROM	PROM	EPROM	EAROM
COST (RANK)	1	2	3	4
PROGRAM TIME	WEEKS	MINUTES	MINUTES	MICROSECONDS
SETUP CHARGE	YES	NO	NO	NO
REUSABILITY	NO	NO	YES	YES
SPEED	FAST	VERY FAST	MEDIUM	SLOW

B. READ-ONLY MEMORY COST/BIT VS FLEXIBILITY

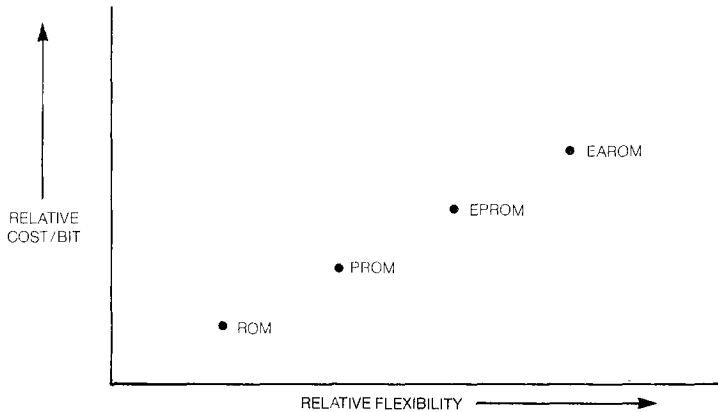


Figure 2-21. Read-Only Memory Overview

THE COMPONENT ROUTE: MISCELLANEOUS COMPONENTS

Included in the full support of the 9900 Family is the large array of SSI, MSI and linear integrated circuits. Information on all components manufactured by Texas Instruments may be found in the following data books:

Power Data Book	LCC4041
TTL Data Book (Second Edition)	LCC4112
TTL Data Book (2nd Edition Supplement)	LCC4162
Transistor and Diode Data Book	LCC4131
Semiconductor Memories Data Book	LCC4200
Optoelectronics Data Book (Fourth Edition)	LCC4230
Optoelectronics Data Book (Fifth Edition)	LCC4410
Linear Control Circuits Data Book	LCC4241
Bipolar Microcomputer Components Data Book	LCC4270
Interface Circuits Data Book	LCC4330
Electro Optical Components	LCC4340
Voltage Regulator Handbook	LCC4350
MOS Memory — 1978	LCC4380
9900 Family Systems Design Book	LCC4400

Correspondence and inquiries about these books should be directed to:

Texas Instruments Incorporated
P.O. Box 225012, M/S 54
Dallas, Texas 75265
(214) 238-3894

Most of the above are concerned with SSI and MSI integrated circuits. The following is a list of additional guides to discrete components.

Optoelectronics Master Selection Guide	CL-346	1978
Discrete Semiconductor Master Selection Guide	CL-347	1978

Correspondence and inquiries about these units should be directed to:

Texas Instruments Incorporated
P.O. Box 225012, M/S 308
Dallas, Texas 75265
(214) 238-2011

THE MODULAR ROUTE: MICROCOMPUTER MODULES

TM990 microcomputer modules are preassembled, pre-tested, ready-to-use combinations of 9900 Family components which are available to meet the needs of the microprocessor and microcomputer systems designers.

An overview of the TM990 microcomputer module product line, divided into the product series, is shown in *Figure 2-22*. A summary of key parameters are given in *Tables 2-1, 2-2* and *2-3*. The series ranges from microcomputers to expansion boards for memory and I/O, to software support in read-only memory (EPROM), to the accessories required to interconnect the modules. An I/O microterminal, TM990/301, is a low-cost terminal for system development included in the 300 series. A module of I/O and memory for software development, the TM990/302, is included in the 300 series and will be discussed further in the software support section.

The additional software products, TIBUG Monitor (TM990/401), Line-by-Line Assembler (TM990/402), and the POWER BASIC units (TM990/450, 451, and 452) will also be discussed in the software support section.

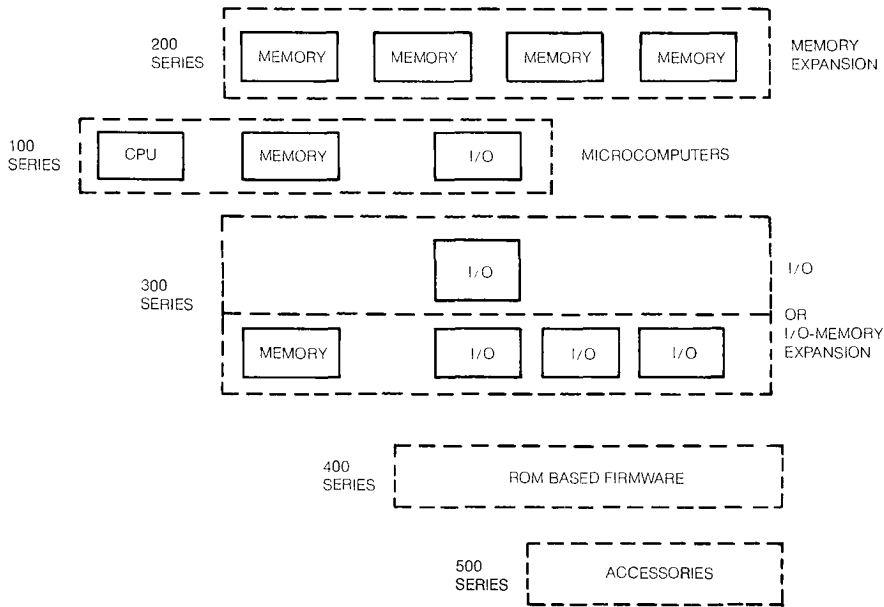


Figure 2-22. TM990 Microcomputer Module Series

The Application

Microcomputer modules are for the system designer who wants to:

1. Apply and evaluate a 9900 Family microcomputer without taking the time for all the engineering, planning, assembly and testing needed to design and assemble the equivalent microcomputer system.
2. Free himself from design details to concentrate on speeding an end product to market.
3. Expand memory of an existing 9900 Family system.
4. Assemble a low-cost software development system to edit, assemble, load and debug programs for PROMs.
5. Expand a university course with low-cost hands-on hardware.
6. Evaluate POWER BASIC programs and apply them to microcomputer systems.

A Special Product

A special product in the microcomputer module series is the TM990/189 University Board. It is designed primarily as a learning tool for the engineer, student or hobbyist. It aids in the instruction of microcomputer fundamentals, machine and assembly language programming and microcomputer interfacing. A tutorial text and a list of assembly procedures are included. More information is found in Chapter 8.

TM990/100 SERIES—MICROCOMPUTER MODULES

Model	CPU	EPROM (Bytes)	RAM (Bytes)	Serial I/O ports	Parallel I/O Lines	Prioritized vectored interrupts	Timers
TM990/100M-1	TMS9900	2K (2708) (Contains TIBUG Monitor) Expandable to 8K (2716)	512 Expandable to 1K	1 RS232C 1 TTY	16	16	2
TM990/100M-2	TMS9900	2K Blank Expandable to 8K (2716)	512 Expandable to 1K	1 RS232C or 1 Differential line driver	16	16	2
TM990/100M-3	TMS9900	8K (2716) Blank	1K	1 or 1 Differential line driver	16	16	2
TM990/101M-1	TMS9900	2K (2708) (Contains TIBUG Monitor) Expandable to 8K (2716)	2K Expandable to 4K	Port A RS232C or TTY Port B RS232C or Modem	16	16	3
TM990/101M-2	TMS9900	2K (2708) Blank Expandable to 8K (2716)	2K Expandable to 4K	Port A RS232C or Multidrop Port B RS232C or Modem	16	16	3
TM990/101M-3	TMS9900	8K (2716) Blank	4K	Port A RS232C or TTY Port B or Modem	16	16	3
TM990/180M-1	TMS9980	2K (2708) (Contains TIBUG Monitor) Expandable to 4K	512 Expandable to 1K	1 RS232C or TTY	16	16	2
TM990/180M-3	TMS9980	4K Blank	1K	1 RS232C or or 1 Differential line driver	16	16	2
TM990/189	TMS9980	4K Expandable to 6K	1K	1 TTY	16	Special features: audio cassette and acoustical indicator	

TM 990/200 Series—MEMORY EXPANSION

PRODUCT	MEMORY TYPE	MEMORY SIZE (BYTES)
TM990/201-41	EPROM/Static RAM	8K EPROM, 4K RAM
TM990/201-42	EPROM/Static RAM	16K EPROM, 8K RAM
TM990/201-43	EPROM/Static RAM	32K EPROM, 16K RAM
TM990/206-41	Static RAM	8K RAM
TM990/206-42	Static RAM	16K RAM
** A*	Dynamic RAM	16/32/64K RAM

second quarter 1979

Table 2-1. Key Parameters of TM990/100 and 200 Series

Table 2-2. Key Parameters of TM 990/ 300 Series Modules

TM 990/300 Series—I/O, I/O-MEMORY EXPANSION

I/O	Microterminal	FE	Displays data and Address
I/O, MEMORY (For Software Development)			
	DESCRIPTION	FEATURES	
	Software development module used in conjunction with TM990/100M or TM990/101M for software development system	Dual audio cassette interface, 2K X 16 RAM, 4K X 16 EPROM, and EPROM programming	
I/O EXPANSION			
PROC 48 bit	or up to 27 unatched interrupts	TEI	S detect latches

Table 2-3. Key Parameters of TM990/400 and 500 Series

TM 990/400 SERIES—ROM BASED FIRMWARE

Product	Description		
TM990/401-1	TIBUG Monitor	M-X	
401-2		2)	
402-1	Line by Line Assembler	2)	
402-2	Line by Line Assembler	1)	
450	8K Byte Evaluation BASIC	4)	
TM990/451	12K Byte Development BASIC	2716 (6)	(Four 2716's on TM990/100, two 2716's on Memory Expansion Board (TM990/201-XX) or Software Development Board (TM990/302))
			TM990/101M-X (Four 2716's on TM990/101, two 2716's on Memory Expansion Board (TM990/201-XX) or Software Development Board (TM990/302))
TM990/452	4K Byte Enhancements to Development BASIC	2716 (2)	TM990/302

TM 990/500 SERIES—ACCESSORIES

Card cage

Product	No. of slots	Slot spacing	Dimensions
	4	1"	
	8	.75"	

Power supply

TM	Input Requirements		Output			
	Frequency	Efficiency	+5V	+12V	-12V	+45V (EPROM programming voltage)
519	57-63 Hz	11%	6.0A	0.9A	0.9A	0.1A
	57-63 Hz	102/132V	2A	250 mA	180 mA	

Universal prototyping boards

Product	Description	Capacity
TM990/512	Unpopulated board for use with wirewrap or solder sockets.	16 pairs of 50 pin columns that accept .3 or .4 centers
TM990/513	Wire-wrap board populated with gold plated pins	16 pairs of 50 pin columns that accept .3 or .4 centers

Analog I/O expansion

To aid in providing the interface between analog and digital signals several companies are supplying products that complement the 9900 microcomputer components family. Key parameters of a number of these products are shown in *Table 2-4*.

A/D and D/A Converters

Product	Resolution	A/D Input Channels	Input Voltage Range	Input Current Range	Throughput Rates	Programmable Gain	D/A Output Channels	Voltage Output Range	Current Loop Outputs	+5V Requirements	Codes
RT1-1240-S	12 Bits	16SE, 8 Diff Expandable to 32SE, 16 Diff	+5V, +10V ± 5V, ± 10V	0-50 mA	40K Chan/sec	1,2,4,8	0	—	—	1.4 A	Binary, Offset Binary, Two's complement
1240-R	"	"	"	"	"	1	0	—	—	"	"
1241-S	"	"	"	"	"	1,2,4,8	2	+5V, +10V ± 2.5V, ± 5V ± 10V	4-20mA	"	"
1241-R	"	"	"	"	"	1	2	"	4-20 mA	"	"
RT	"	0	—	—	10 μ sec Setting	—	4	"	—	"	"
RT	"	0	—	—	"	—	8	"	—	"	"

Analog Devices—Route 1 Industrial Park, P.O. Box 280, Norwood, Massachusetts 02062, (617) 329-4700

Product	Resolution	A/D Input Channels	Input Voltage Range	Input Current Range	Throughput Rates	Programmable Gain	D/A Output Channels	Voltage Output Range	Current Loop Outputs	+5V Requirements	Codes
ANDS 1001	12	16SE/8 Diff Expandable to 64SE/32 Diff	+5V, +10V ± 5V, ± 10V	0-50 mA	30K Chan/sec	—	0	—	—	700 mA	Binary, Offset Binary, Two's complement
ANDS 1002	15 Bit + Sign Bit	1-4	± 20mv, ± 40mv ± 80mv thermo-couples	—	10 samples/sec	—	0	—	—	—	"
ANDS 2001	12	0	—	—	10 μ sec Setting	—	1-4	+5V, +10V ± 5V, ± 10V	4-20 mA	—	"
ANDS 3001	12	16SE/8 Diff	+5V, +10V ± 5V, ± 10V	0-50 mA	30K Chan/sec	—	2	"	4-20 mA	—	"

Analogic—Audubon Road, Wakefield, Massachusetts 01880, (617) 246-0300

Table 2-4. Key Parameters for Analog conversion units for I/O Expansion

THE MINICOMPUTER ROUTE

For large system applications in which the computer system is a small portion of total system costs, use of prepackaged OEM minicomputers as system components provides a number of advantages. A full complement of system and applications software is readily available for immediate use on the machine, including assemblers, linkers, editors, operating systems, high level languages, a variety of utility packages, many applications packages, and much, much more.

Texas Instruments Digital Systems Group manufactures two minicomputers which are compatible with the TMS9900. The first is the 990/4 minicomputer which uses the TMS9900 as its central processing unit. It utilizes the CRU for control of peripheral devices making this system directly compatible with the 9900 Family. The second minicomputer implements the CPU in TTL, maintaining upward compatibility with the 9900 Family. This unit, the 990/10 uses a DMA peripheral device interface called TILINE™ for control of high speed peripherals such as magnetic tape units and moving head disk drives, and provides extended addressing capability.

A complete discussion of the use of these systems as OEM system components is beyond the scope of this book, but further information may be obtained by writing:

Texas Instruments Incorporated
Digital Systems Group
P.O. Box 1444
Houston, Texas 77001
Attention: Market Communications M/S 784

or contact your local TI sales office or distributor system center listed in the appendix.

The 990 Computer Family Systems Handbook, the 1978 Catalog of the 990 Computer Family, and the 990 Computer Family Price List provide detailed information on the use of 990 computers as OEM system components.

A SELECTION PROCESS

Criteria for selecting a microprocessor, microcomputer, microcomputer component peripheral, or a minicomputer for a system application are listed in *Figure 2-23*. System performance, cost, reliability, and delivery may also depend on the vendor that designs and supports the products used.

<p>MPU ARCHITECTURE</p> <ul style="list-style-type: none"> Word Size Number of Instructions Address Bus Length Data Bus Length I/O Bus Length Clock Rate Benchmark Performance (Selected Functions) Arithmetic Capability <ul style="list-style-type: none"> Multiply Divide <p>I/O CAPABILITY AND PERIPHERAL CIRCUITS</p> <ul style="list-style-type: none"> Parallel I/O <ul style="list-style-type: none"> How Many Bits Data Rate Programmability Drive Required Serial I/O <ul style="list-style-type: none"> Asynchronous Synchronous Baud Rate EIA Current Loop Timers and Event Counters <ul style="list-style-type: none"> Interval Max Count Interrupts <ul style="list-style-type: none"> Number Masking DMA <ul style="list-style-type: none"> Channels Chaining Required Other Interfaces <ul style="list-style-type: none"> Floppy Disk Analog Keyboard CRT Tape 	<p>MPU (other specifications)</p> <ul style="list-style-type: none"> Package Temperature Range Supply Voltages Power Consumption Special Reliability Unit Costs (Selected Volumes) <p>System Environmental</p> <ul style="list-style-type: none"> Supply Voltages Temperature Range Power Consumption Special Reliability Special Size <p>Support</p> <ul style="list-style-type: none"> Technical Documentation Hardware Development Support Emulators Testers Evaluation Modules <p>Software</p> <ul style="list-style-type: none"> Assemblers Text Editors Simulators Utilities Application Libraries High-level language <p>Software Development</p> <ul style="list-style-type: none"> Systems <ul style="list-style-type: none"> Cross-Support Dedicated
---	--

Figure 2-23. Selection Criteria for Microprocessor, Microcomputer Systems

Vendor Selection

One way of evaluating a vendor is to make a list of items similar to the selection criteria for system components. Some of the same items from this list, especially in the support area, can be included. Additional items for consideration are shown in *Figure 2-24*.

DOCUMENTATION	CREDIBILITY
Product	Reputation
Support Systems	Investment
Applications	Financial Status
MANUFACTURING CAPABILITY	CUSTOMER SUPPORT
Facilities	Application Engineers
Product Levels	Distribution
Backlog	Hot Lines

Figure 2-24. Vendor Criteria

Setting weights for each item and summing these for individual vendors allows a direct comparison. The total number accumulated for each vendor establishes a vendor rating.

9900 FAMILY SOFTWARE AND DEVELOPMENT SYSTEMS

IMPORTANCE OF SOFTWARE

As described in Chapter 1 (*Figure 1-9*), the term software is used to describe the programs and documented ideas which allow small amounts of general purpose hardware (microprocessors, memory, peripherals) to replace large amounts of special purpose hardware. The costs for software are becoming a much larger percentage of the total system development cost. These costs are primarily incurred prior to production of a system. For large volume systems the share of these one-time costs attributed to each unit is small since the total software costs are divided by a very large number. Correspondingly, when the volume of units produced is low, the software cost per unit will be quite high. This factor, coupled with a lack of familiarity, has led many users to underestimate software development costs.

Since software now commands 80% of the design effort of complete systems, and since many software tasks are common to the industry, the level of software support from a vendor can have tremendous impact on total system design cost. Perhaps more importantly, availability of a wide variety of system and application software packages can drastically shorten design time and speed the product to market.

SOFTWARE DEVELOPMENT SYSTEMS

Development of software requires equipment — program or software development systems. As a system designer makes a decision to use a microprocessor or microcomputer, all design avenues seem to focus on software development. Questions naturally arise, “How can I do software ‘breadboarding’ and program testing?”, “How can I arrive at a final program and be assured that it is correct?” and “Can it be done economically?”

Figure 2-25 illustrates cost versus capability for each of the program development systems that support the 9900 Family. Lower cost systems tend to have lower capability. The choice of a program development system depends on many factors. Some examples are: (1) *Capital Status* — capital availability determines whether a firm can consider the sophisticated emulator systems which boost designer productivity. (2) *Equipment on Hand* — availability of a terminal, line printer, or EPROM programmer or other useable equipment would likely reduce the required level of investment. (3) *Equipment Longevity* — How long the equipment will be used may allow division of the cost of the equipment over several projects. (4) *System Complexity* — Highly complex applications often require the best development tools possible; therefore, the most sophisticated system is required or the job can't be done. (5) *Production quantities* — High volume applications can more easily bear the cost of top-of-the-line development equipment; the corresponding increase in productivity made possible by this equipment, increases design efficiency. (6) *In-House Computer Capability* — Availability of in-house computer support makes development via timeshare cross-support an efficient alternative.

A brief description of the program development systems follows:

Program Development Systems

1. TM990/189— University Board. (Price: less than \$250) This board provides an inexpensive means of evaluating the 9900 Family and learning about microprocessors in general. It comes with a debug monitor and assembler. Key features include full alphanumeric keyboard; display via 10 seven-segment digits; 16-bit parallel, RS232, TTY, and audio cassette interface; and a tutorial text and hardware reference manual. (See Chapter 8.)

2. TM990/100M— Microcomputer with line-by-line assembler

TM990/301— Microterminal for programming (combined price: less than \$500)

(*Figure 2-26*). These components are described in detail in Chapters 3 and 8. Basic program benchmarks may be written and tested with the 9900 microcomputer. A terminal such as a 743 KSR may be connected to the board and additional development software used. (This technique is described in Chapter 9.)

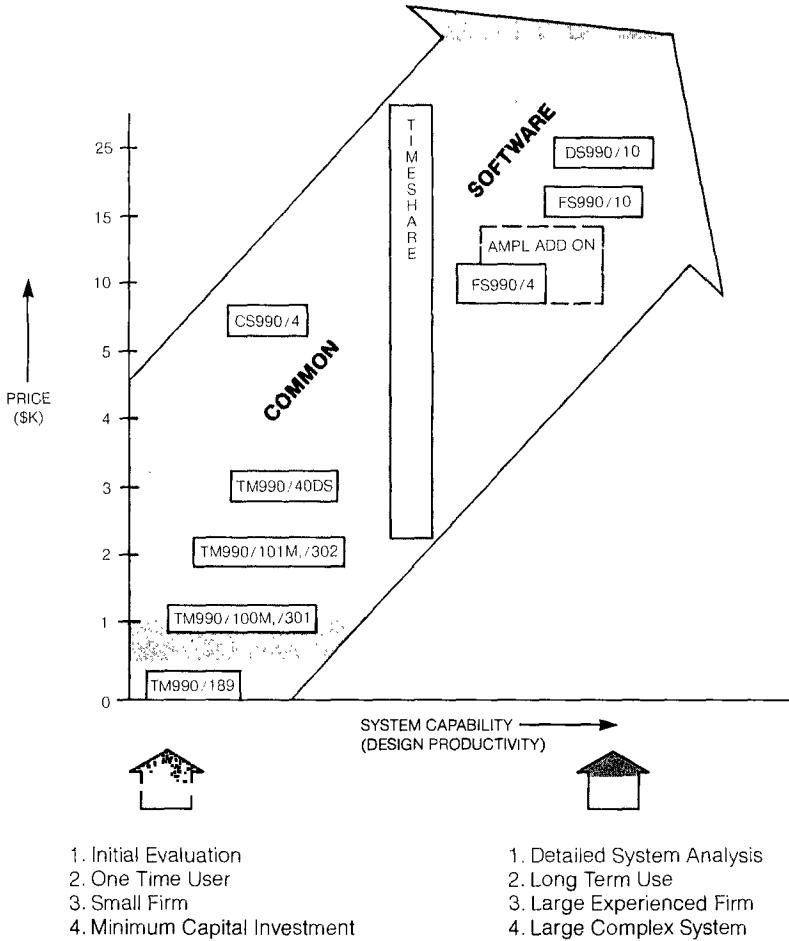
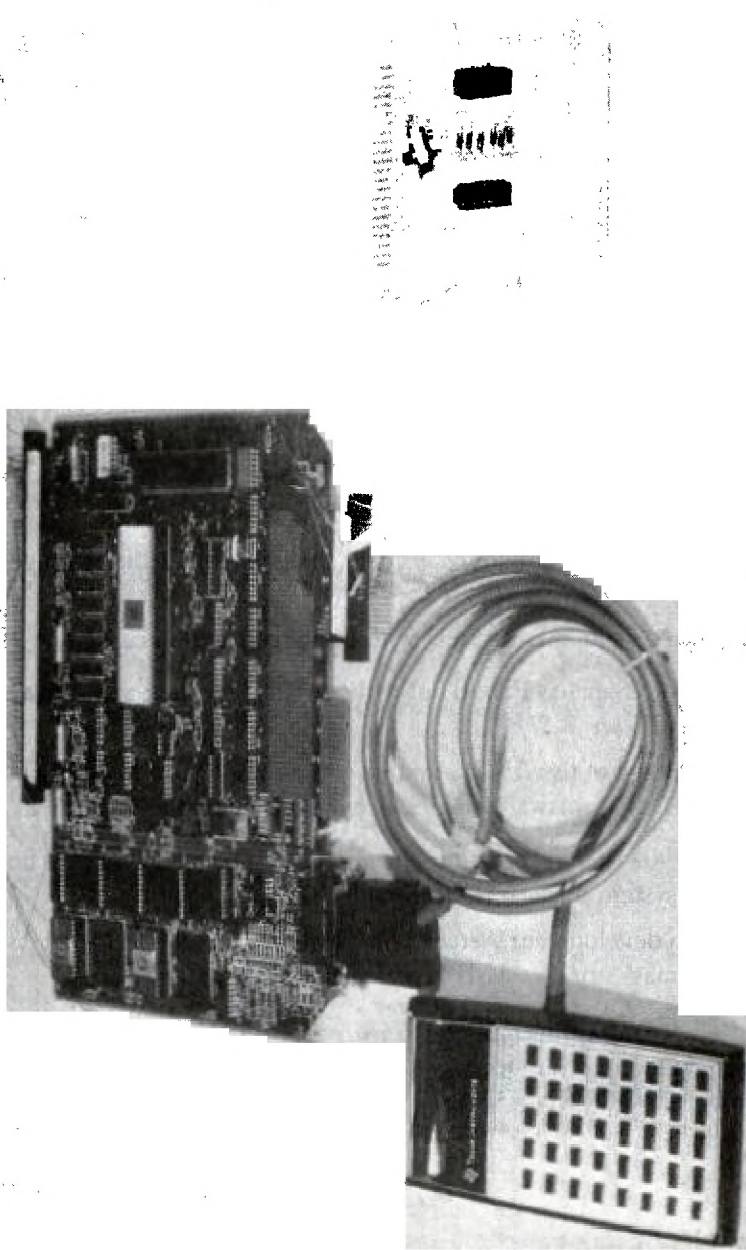


Figure 2-25. Cost vs. System Capability for 9900 Family Program Development Systems



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Figure 2-26. TM990/100M Microcomputer with TM990/301 Microterminal

3. TM990/302— Microcomputer board (price: less than \$600)

Software is on the board in the form of EPROM devices for editor, assembler, linker, debugger, and EPROM programmer functions. A terminal and one or two cassette recorders are needed to complete a very powerful, yet very low cost program development system. The /302 is a companion to (or extension of) the TM990/100M or /101M board. (*Figure 2-27*).

4. TM990/40DS— TMS9940 development system (price: less than \$2800) containing an EPROM programmer for the TMS9940E, Debug Monitor, Assembler and Trial In-System Emulation; the /40DS provides development capability and emulation of most of the TMS9940's operations (*Figure 2-28*).

5. CS990/4— 990/4 minicomputer with a 733 ASR dual cassette terminal (price: less than \$6000) (*Figure 2-29*).

Program development software is available on cassettes to perform every task outlined previously.

6. FS990/4— 990/4 minicomputer, terminal, and dual floppy disk storage unit (price: less than \$12,000) (*Figure 2-30*).

Complete program development system with peripheral add-on capacity.

7. FS990/AMPL— Same as FS990 but with AMPL hardware and software added (price: less than \$20,000) (*Figure 2-31*).

The primary advantage of the AMPL system is the complete hardware debugging capability via the AMPL software and 9900 emulator and trace functions.

8. FS990/10— 990/10 minicomputer (*Figure 2-32*), terminal, and dual floppy disk storage unit (base system starts at \$15,000).

Complete program development system which can be upgraded to include moving-head disk mass storage. AMPL is available as an option.

9. DS990/10— 990/10 minicomputer (*Figure 2-33*), terminal, moving head-disk mass storage with complete multi-user system software (base system starts at \$25,000). Supports Macro-Assembler, FORTRAN, BASIC, PASCAL and COBOL.

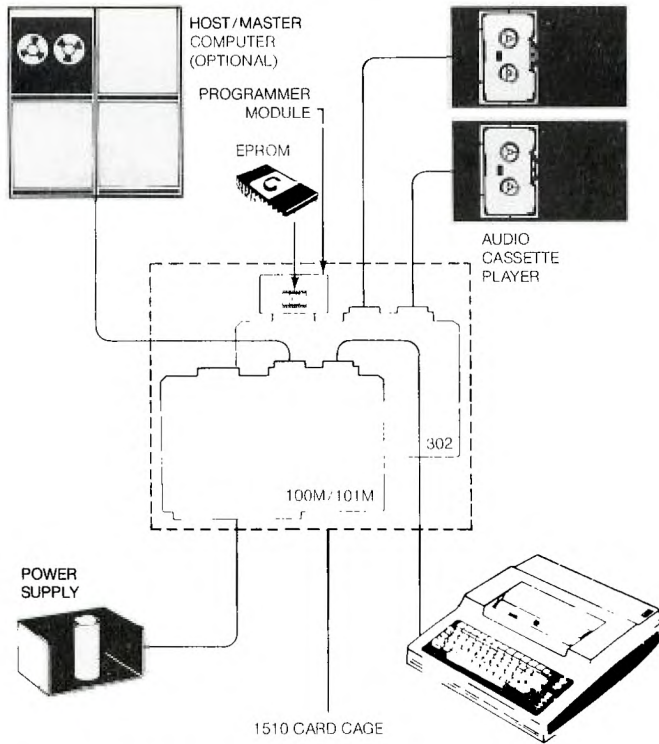


Figure 2-27. TM990/302 Program Development System

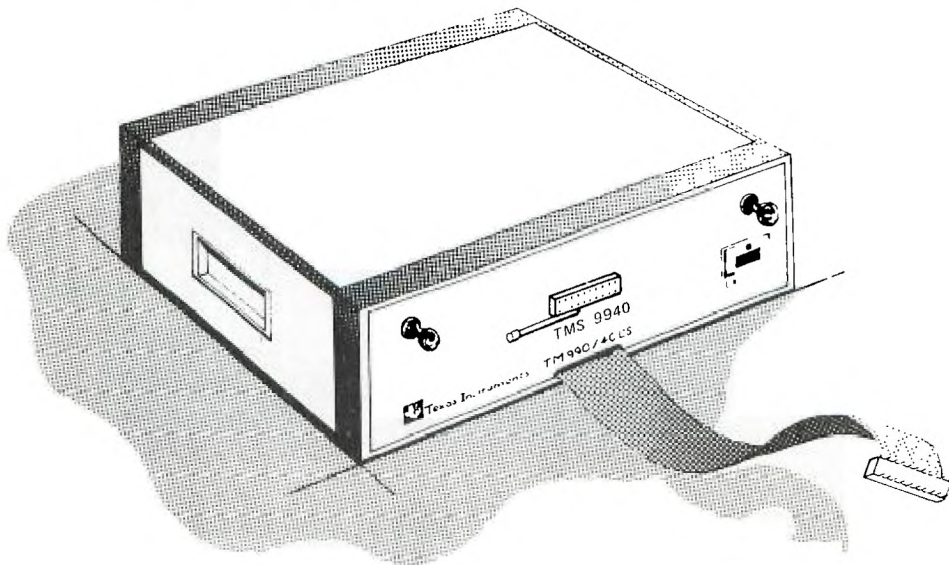


Figure 2-28. TM990/40DS cables and card chassis

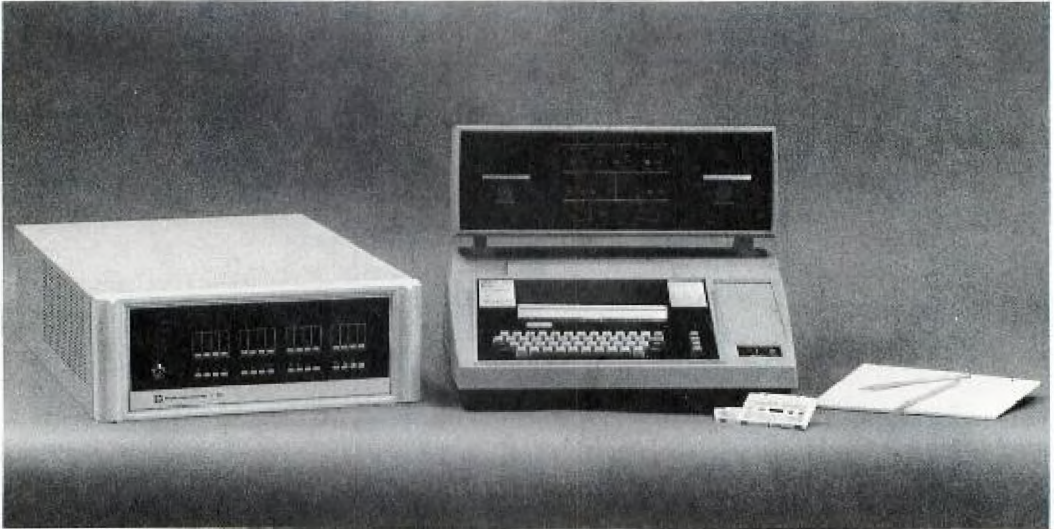


Figure 2-29. CS 990/4 Software System



Figure 2-30. FS990 Software Development System
(with optional printer)

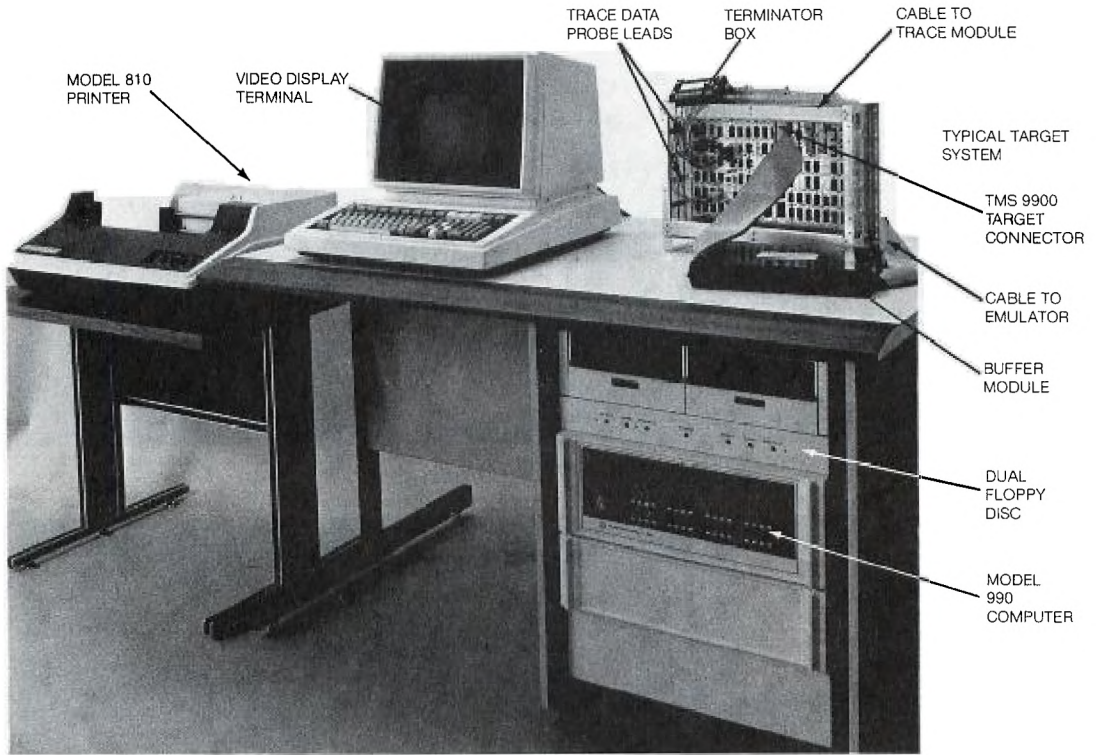


Figure 2-31. Typical AMPL Microprocessor Prototyping Laboratory



Figure 2-32. FS990/10 Minicomputer System

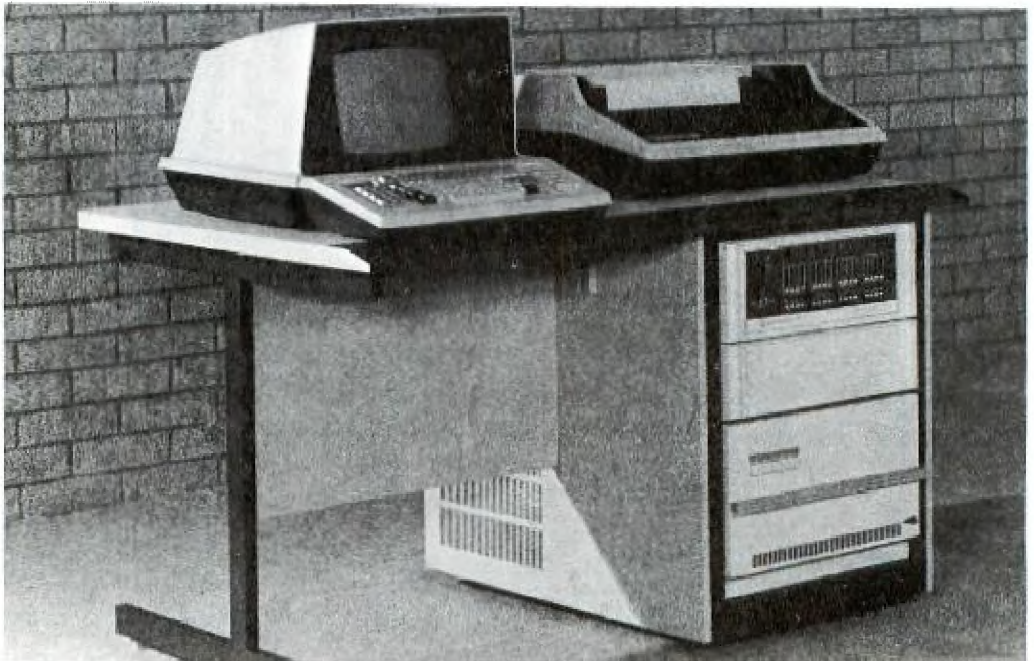


Figure 2-33. DS990/10 Minicomputer System

Which Program Development System to Use

The choice of a program development system requires evaluation of an application's specific requirements. The lowest cost system (TM 990/100M board and /301 microterminal) will allow a very basic level of programming, and is suitable for writing short routines to test algorithms or evaluate execution speed. Since labels are not allowed and there is no editing program to help add or delete program steps, programming is relatively difficult.

By adding the TM990/302 Software Development Module (with the TM990/100M or 101M) programming becomes much easier. An editor program helps you modify the program steps, the assembler allows labels, and the other elements—debug, EPROM programmer, relocating loader, and I/O handlers—add substantial programming flexibility. A programmer might well evaluate this system as being an order of magnitude better than the /100M board alone. It is best suited for one designer working on a single prototype.

But there are limitations to the /302. The system depends on cassette recorders for storage of development software and user programs. And cassettes are slow. The number of times per day that a programmer can make a change in his program, process it through the system, and test the results is generally in the range of three to five.

The number of program change cycles per day can be increased by purchasing a CS990 system. This digital cassette based software development system, being more versatile, can increase daily program iterations to about ten. Two or three programmers can use a single system comfortably.

The FS990/4 system uses floppy disk storage to further improve flexibility. Daily program iterations can be over 20. Because program turnaround is fast, a single FS990 system is often used by several programmers.

By adding AMPL hardware and software the FS990 system can be upgraded to an AMPL prototyping system. Hardware testing may be performed under program control.

The chart shown in *Figure 2-34* shows the different levels of sophistication of program development systems that can be used with each 9900 CPU.

2 <

SELECTED PROCESSOR	TMS9900/ SBP9900A	TMS9980A/ TMS9981	TMS9985	TMS9940
MINIMUM SYSTEM	TM990/100M TM990/101M TM990/302	TM990/189 TM990/180	TM990/185	TM990/140
MEDIUM SYSTEM	CS990/4	CS990/4	CS990/4	TM990/40DS
LARGE SYSTEM	FS990/4 AMPL FS990/10	FS990/4 AMPL FS990/10	FS990/4 AMPL FS990/10	FS990/4 AMPL FS990/10
MAXIMUM CAPABILITY	DS990/10	DS990/10	DS990/10	DS990/10
TIMESHARE TMSW101MT GE, NCSS, Tymeshare	X X	X X	X X	X X

Figure 2-34. Program Development Systems for Each 9900 Family CPU

Timeshare

Timeshare users approach software development in one of two ways. Either they purchase and install the TMSW101MT cross-support package on an in-house computer, or they lease access to a similar package on a commercial timeshare system such as GE TERMINET, NCSS, and TYMSHARE. Both approaches provide a 9900 cross-assembler compatible with the FS990 prototype development system. Both also provide a simulator and ROM utility. In-house users often interface the ROM utility directly to EPROM programmers. Otherwise several printout formats are available to match standard ROM and PROM order techniques.

The timeshare approach provides high-level development capability at minimum initial cost. It does, however, incur large operating costs, especially when using commercial systems.

SUPPORT SOFTWARE AND FIRMWARE

The program development systems and the 9900 Family of components are supported by a full line of software. The chart shown in *Figure 2-35* summarizes the capability of the program development system software.

PDS		CROSS-SUPPORT						DX990
PROGRAM STEP		TMSW101MT	TM990/302	TM990/40DS	PX990	TX990	FS990 AMPL	W/AMPL
EDIT		X	X		X	X	X	X
ASSEMBLE		X	X	X	X	X	X	MACRO
LINK		X			X	X	X	X
LOAD		CREATES LOAD MODULE	X	X	X	X	X	X
DEBUG		X	X	X	X	X	X	X
E.PROM				X			X	X
LOGIC TRACE							X	X
SIMULATOR		X						
READ-ONLY MEMORY PROGRAM- MING	ROM	X				X	X	X
	PROM	X	X	X	X	X	X	X

Figure 2-35. 9900 Family Software Development System Capabilities

Additional software and firmware are as follows:

TM990/401 — TIBUG Monitor

The TMS990/401 TIBUG Monitor is a comprehensive, interactive debug monitor in EPROM included in the basic price of the TM990 CPU modules. TIBUG includes 13 user commands plus six user accessible utilities and operates with 110, 300, 1200 and 2400 baud terminals. The basic TIBUG functions include:

1. Inspect/change the following: CRU, memory locations, program counter, workspace pointer, status register, workspace registers.
2. Execute user programs under breakpoint in single or multiple steps.

TM990/402 — Line-by-Line Assembler (LBLA)

TM990/402 is a line-by-line assembler which is supplied pre-programmed in EPROM for immediate system use. By allowing the entry of instructions in mnemonic form and performing simple address resolution calculations with a displacement range of +254 to -256 bytes, the assembler is an extremely powerful tool for assembly language input of short programs or easy patching of long programs.

POWER BASIC High-Level Language

POWER BASIC, an easy-to-use extension of the original BASIC language, is highly suitable for the majority of industrial control applications. It greatly simplifies the solution of complex system problems and eliminates unnecessary design details.

POWER BASIC can be used for a general system implementation language as well as for information processing. It is also versatile enough to solve problems in real-time control of events while improving programmer efficiency in implementing complex algorithms.

The performance of POWER BASIC is outstanding — 2 to 3 times faster than any existing 8-bit microcomputer-oriented BASIC. In effect, you get minicomputer performance at microcomputer cost.

Other advantages of POWER BASIC include:

- Full string processing capability
- Multidimensional arrays
- 13-digit arithmetic accuracy
- Automatic minimum memory configuration

POWER BASIC language interpreters are available in economical yet versatile packages shown in *Table 2-5*.

Table 2-5. POWER BASIC Firmware

PART NO.	MEDIA	NAME	DESCRIPTION
TM990/450	EPROM device kit	Evaluation POWER BASIC	Reduced memory version (8K byte) designed to offer evaluation tools for exploring POWER BASIC applications.
TM990/101M-10	*TM990/101M		ROM kit executes standalone on TM990/100M, 101M modules.
TM990/451	EPROM device kit	Development POWER BASIC	Expanded memory version (12K byte) providing capability for design, development, and debug of POWER BASIC programs. Executes on TM990/201 or 302 module interfaced with TM990/100M, 101M CPU modules.
TM990/452	EPROM device kit	Enhancement of Development POWER BASIC Software Package	Provides EPROM programming, dual audio cassette handling, and I/O utilities for TMS990/302.
TMSW201F	FS990 diskette	Configurable POWER BASIC	Fully expanded version including complete diskette file support and a configurator program which reduces the size of POWER BASIC programs for execution.

*Contained in TM990/101M Module

PASCAL High-Level Language

TIPMX Executive Components Library in PASCAL

TIPMX is a configuration of software processes that provides executive functions such as multitask priority scheduling, interrupt servicing, and inter-process communication. It relieves the programmer of the necessity to develop these processes. TIPMX also supports, but is not limited by, PASCAL data structures and program structures.

A tailored TIPMX is configured by selecting desired processes from a library of system and run-time support modules. These processes are link-edited to form a supervisory nucleus which is loaded into EPROM memory to enhance its speed, efficiency and reliability.

PASCAL, FORTRAN or Assembly Language processes then execute under the auspices of this tailored TIPMX executive.

2