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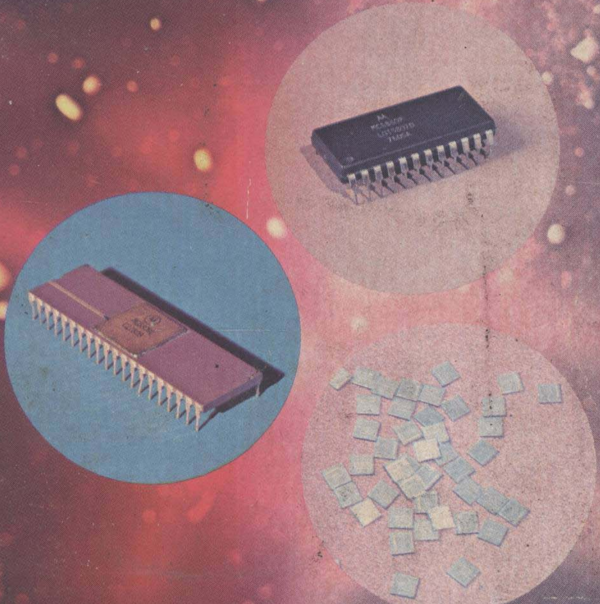
# How to Build Your Own Working 16-Bit Microcomputer



Everything you need to know to use the new super
…nced TI 9900 CPU single-chip processor.

Ken Tracton

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# How to Build Your Own Working 16-Bit Microcomputer

By Ken Tracton

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# Preface

Microprocessors, those tiny slices of processing power, are rapidly growing more potent. The first microprocessor was suitable only for simple controller operations (such as the control unit of a microwave oven). Its immediate successors had a greatly increased instruction set, but were limited to 4-bit data chunks. These chips remain with us, as the processors in calculators. Within a year, both 8- and 12-bit units reached the market, and the microcomputer as we know it was born. Now, we are able to build 16-bit processors that can compete on equal terms with mini computers, both in speed and in capability.

One such device, the 9900 CPU by Texas Instruments, is widely considered to be the most advanced single-chip processor yet built. This text describes how to design a working *micro-computer* with the 9900 and its support family.

It begins with a minimum unit, useful for machine language and control functions, and progresses to an information processing system that can include time-sharing, a variety of languages, floppy-discs, disc-drives, cassette tape units, and a host of different terminals. En route, it discusses each type of interface required, how to use it, and how, on occasion, to circumvent its necessity.

The appendices include 9900 instruction codes, pinouts of the 9900 support chips as described in the text, and a listing of the ASCII code in near-universal use.

I would like to thank Mr. Alec Grynspan, who compiled the vast amount of data required for this text and assisted me in many different capacities. I must also give special thanks to Mr. Dave Campbell, representative of Texas Instruments for his cheerful and understanding help which made this book possible, and of course Texas Instruments who created the 9900 family of micro-processor devices and peripherals, who graciously supplied the materials that allowed me to evaluate the information.

Ken Tracton

# Contents

# Introduction to Microprocessors

# 1

The first microprocessors were 4-bit types which handled data as 4-bit nybbles. The earliest of this new breed of machines, the Intel 4004, was a major breakthrough. It was quickly followed by the Intel 4040, and the National Semiconductor IMP-4.

The 4-bit microprocessors are, for the most part, considered obsolete. The exceptions are the one-chip microcomputers, with storage and interfaces, as well as control on a single chip. These are excellent controllers and have been used in such devices as sewing machines, CRT controllers, and TV games.

An example is the TMS1000-series microprocessor, made by Texas Instruments (TI), consisting of the TMS1000, TMS1100, TMS1200, and TMS1300 processors. These consist of one-chip microprocessors containing from 1024 to 2048 bytes of read only memory (ROM), a central processing unit (CPU), 32 to 64 bytes (addressed as 64 to 128 nybbles) of random access memory (RAM) for a scratch pad, and simple input/output (I/O) logic.

These chips are incredibly low in cost when one considers their power and versatility; with their various kin, they have completely changed the electronics and controller fields.

Although the Intel 4004 set the world on its ear, the first 8-bit units, of which the Intel 8008 is the most famous, turned it upside down.

The smallest minicomputer being taken seriously were 8-bit (1 byte) processors, and suddenly there was a complete computer on a chip.

In actuality these first 8-bit machines were bigger versions of the 4-bit types and meant to be used as controllers, not as computers. Their instruction set and interfacing requirements were oriented towards process control. Even so, the hobbyists started using them for other purposes and quickly started up that class of systems called microcomputers.

Microcomputers are now used in such sophisticated devices as (a) pocket computers, more powerful than the early monsters in the computer industry; (b) desk-top computers, capable of serving such diverse users as car dealers and small motels and hotels; (c) office computers, for the accountant and business man; (d) TV games, of such sophistication that one of these units can play hundreds of different games, controlled by the insertion of a small tape cartridge, and (e) robots, capable of such far-ranging feats as controlling Mars and Jupiter probes to as mundane feats as delivering the office mail.

The number of 8-bit machines has grown enormously, and is always in flux, with newer models available almost daily. The following is a list of some of the better known 8-bit microprocessors:

- F8 by Fairchild
- 3870 by Mostek
- SC/MP by National Semiconductor
- 8080 family by Intel
- Z80 by Zilog
- 6800 family by Motorola
- 6500 family by MOS Technology
- 2650 family by Signetics
- COSMAC 1802 family by RCA

## THE 12-BIT MICROPROCESSOR

This microprocessor is a lonely creature, standing by itself in terms of the number of variations available. The IM-6100 from Intersil duplicates the Digital Equipment Corp. (DEC) PDP-8 almost perfectly.

The PDP-8 has one enormous feature going for it that makes the soft-ware-compatible IM-6100 very popular and tempting, that is, the software of the PDP-8. It is this colossal amount of material that almost compensates for the primitive instruction set capability of the IM-6100.

In languages alone it outstrips any other microprocessor (as well as some much larger machines), having;

| | |
|---|---|
| A) DIBOL | DEC business language |
| B) ALGOL-60 | the subroutine definition language |
| C) FORTRAN | the most famous scientific language |
| D) SNOBOL | string manipulation language |
| E) APL | the mathematical language |
| F) LISP | the artificial intelligence language |
| G) BASIC | the most popular language of all |
| H) FOCAL | a supercalculator language |
| I) LIBRA | time-sharing FOCAL |
| J) MACRO | a macro-assembler for machine language users |
| K) LINK-EDITOR | for hooking everything together |
| L) DOS | for developing systems |
| M) TSS | time-sharing system |

If the PDP-8 or IM6100 has all this power, then why, you may ask, isn't this book written solely on the construction of this machine? The main reason is that I feel that the TI TMS9900 microprocessor is fresh ground for the microcomputer user, with even more potential than the PDP-8.

Other reasons include the most advanced architecture of any true microprocessor is currently within the TMS9900; the TMS9900 has the greatest flexibility of any microprocessor yet developed; the TMS9900 has the best instruction set of any microprocessor, exceeding many minicomputers; and the software development pace for the TMS9900 is increasing exponentially.

While there are so-called microprocessors with power just as great as the TMS9900 (the DEC LSI-11 includes floating point as an option) they are either not as cost-effective or not as flexible (e.g., the LSI-11 could never be used as economically to control a CRT or other smart devices). The LSI-11/2 now consists of separate CPU, memory, and interface cards, but the CPU is not available as a chip or chip group without the card.

## THE 16-BIT MACHINES

Just as the 8-bit microprocessors absorbed and expanded the low end of the minicomputer industry, the 16-bit versions are beginning to make themselves felt in the main stomping grounds of the minicomputer field.

The 16-bit unit, unlike its cousin the 8-bit type, is not really a microprocessor, but is in reality a minicomputer using large-scale integration (LSI) technology. The main 16-bit machines are;

- 9440 by Fairchild
- MicroNOVA by Data General
- CP1600 by General Instruments
- Pace by National Semiconductor
- TMS9900 family by Texas Instruments
- MC2 by Hewlett-Packard
- LSI-11 by DEC

The Fairchild 9440 is an exact duplicate, in terms of instruction set, of the Data General NOVA, while the Data General microNOVA is an extended version of the same machine, with built-in stack and hardware multiply and divide.

The DEC LSI-11 is an LSI version of their PDP-11 minicomputers.

The NOVA was designed as a 16-bit version of the 12-bit PDP-8 with added capabilities that eliminated some of the limitations inherent in the PDP-8. This does not mean that the instructions were simply expanded, but that the concept was expanded.

From this we can see that the IM6100, the 9440, the microNOVA, and the LSI-11 are all minicomputers in the guise of microprocessors.

Although the other 16-bit machines may have much to recommend them, they are not felt by myself to be as desirable.

This book is oriented towards the person wishing to construct a machine and not simply buy a completed unit. For instance, Hewlett-Packard MC2 is used by Hewlett-Packard and is not, at this time, available to anyone else.

The LSI-11 is a multichip system, already designed, and is not available as a separate chip set. This makes sense if we remember that it is meant to duplicate a PDP-11 as a whole and variations would defeat the original design purposes.

Although the 9440 and the microNOVA are available as separate chips and chip sets, they are meant to exactly duplicate the NOVA system by Data General.

## WHY THE 9900?

The TI 9900 was chosen for this book for several reasons; it is an LSI minicomputer rather than a microcomputer chip (microprocessor) in the usual sense of the word. This means that, for the hobbyist or professional, the instruction set and architecture are simple and clean, with little to interfere with designing hardware or software.

The minimum system (see Chapter 4 for a block diagram) is not significantly more expensive than a minimum system using other processors, and may even be less expensive, particularly when compared to other 16-bit processors.

The 9900 is a 16-bit machine with byte addressing and a general register bank (16 registers); it is a 64-pin chip with separate lines for data and addresses, making complex interfaces unnecessary; and it does not require the use of complex memory systems to operate, allowing easy mixing of different memories.

The family of 9900 chips is complete, allowing powerful systems to be designed with ease. There exists currently a version of the TMS9900, called the TMS9980, which can use 8-bit modules and is totally software compatible with the 9900.

The 9900, while still young in terms of software, has most of the key software already available, such as:

1) COBAL—full ANSI COBOL compiler
2) FORTRAN—a re-entrant, full ANSI/ISO compiler
3) A real-time multiprogramming, time-sharing operating system with all the bells and whistles.
4) BASIC—A time-sharing BASIC

The 9900 is available as a one-card computer called the 990/4, as a one-card computer with on-board RAM and ROM called the 990-100M, a TTL version with memory mapping to two-million bytes, called the 990/10. There also exists an $I^2L$ version, with higher speed and pin compatibility termed the IBP-9900. There is the 9980 (8-bit compatible) version of the 990-100M called the 990-180M. And of course the TMS9900, TMS9980, and the IBP9900 are all available as separate chips, along with the rest of the family chips.

All in all I feel that the TMS9900 (or the IBP9900), as a personal computer, is an excellent choice.

## WHAT IS IN THIS BOOK

The 9900 chip itself is obviously covered in detail, since this is the central processing unit, the very nucleus of the computer system.

The 9901 is a programmable systems interface, which provides the 9900 with an interval timer, an event timer, up to 16 I/O ports, and up to 15 interrupt input lines.

The 9902 is an asynchronous communication controller (ACC), which allows interfacing the 9900 to such devices as teletypewriters of all kinds, CRT terminals, hard-copy terminals, paper tape readers, and punches and cassette tape interfaces.

The 9904 is a clock generator which generates all the synchronization signals for the 9900, the 9901, etc.

The 9903 is a synchronous communication controller which eliminates the need for software for the protocols, such as binary synchronous (often called bi-synch), synchronous data link control (usually SDLC), and almost all other synchronous protocols, with the link synchronization and control handled by this chip, the 9903.

# The TMS9900 Processor Chip

# 2

The TMS9900 is a single IC in a 64-pin dual inline package. This package (Fig. 2-1) is larger than the more familiar 8-bit microprocessor chips. The 9900 is 3.2 inches long, and the two rows of pins are 0.900 inch apart rather than the 0.600 inch spacing used in 40-pin packages. Adjacent pin spacing is the familiar 0.010 inch. Pin number 1 is identified by an index dot between Pins 1 and 2.

The chip is produced by N-channel silicon-gate MOS technology, and requires three power supplies for its operation. The recommended levels for these supplies are −5, +5, and +12 VDC. Under typical conditions, the chip draws 50 ma from the +5 VDC supply 75 ma is rated maximum), 100 microamps from the −5 VDC rail 1 ma maximum), and 25 ma from the +12 VDC source (45 ma maximum).

All signal levels (except for the four clock signals), both input and output, are compatible with TTL logic. The clock signals must not be lower than +3 V at their positive points, and TTL guarantees only a +2.4-volt level for a HI signal. If the recommended TIM9904 clock chip is used to provide the clock signals you will have no problem; TTL normally provides adequate drive, but this is not guaranteed.

Maximum clock frequency is 3 MHz, and four non-overlapping phases must be supplied. The 9904 circuit uses a 48-MHz crystal, or a 12-MHz external oscillator, to provide these requirements. Fig.

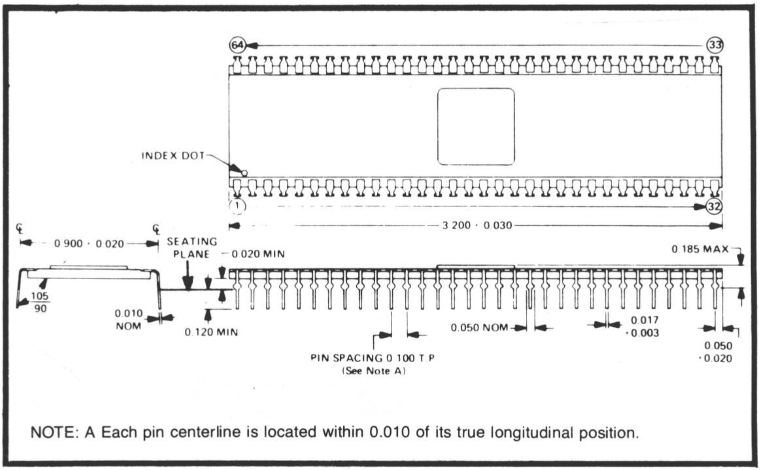


Fig. 2-1. The 64-pin dual inline package of the TMS9900 is larger than the more familiar 40-pin DIP configuration used by 8-bit microprocessors. Added 24 pins make possible more system interconnections. (Courtesy of Texas Instruments)

2-2 shows clock signal timing requirements. The times shown are for maximum-frequency operation. For operation at slower speeds, the duration of individual phases may be extended but the 5-ns guard times between signals should remain unchanged.

Input lines to the TMS9900 all have high impedance to minimize loading on signal sources. Outputs are all capable of driving two

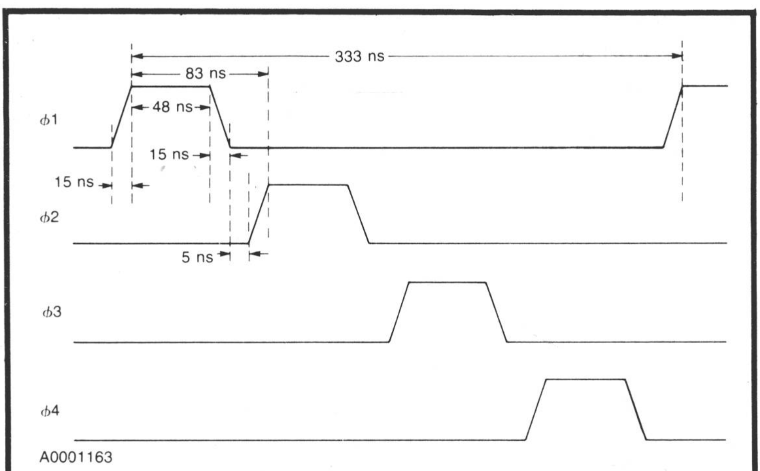


Fig. 2-2. Clock waveforms required by TMS9900 when operating at maximum 3-MHz frequency are shown here. Dead space of 5 ns between phases is essential to proper operation of processor. (Courtesy of Texas Instruments)