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HOW TO BUILD YOUR OWN WORKING MICROCOMPUTER

A step-by-step, start-to-finish guide to putting together a complete, working microcomputer system!

BY CHARLES K. ADAMS

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Preface

A computer is a fascinating device. It is an extension of the operator, capable of doing many intriguing things. It is under complete control of the operator, ready to do what is commanded. Recent advances in semiconductor technology have made it possible to build a computer on a single circuit board. This computer is not the complex monstrosity normally considered as a computer. Instead, it is a relatively simple device with a versatile, yet easily used instruction set. One person, with the desire, can build and program such a computer.

This computer, called a microcomputer, can be assembled with a handful of chips at a very reasonable cost. These microcomputers are based on the microprocessor, which is a very complex circuit, integrated into one large scale integrated circuit. Yet, all the chips required are readily available.

This book is about building and programming a computer. The computer is a relatively simple microcomputer by todays standards, but when compared to computers of twenty years ago it is very advanced and more than capable.

The computer is an expandable, usable computer, complete with programming instructions. This book is designed to take the reader through the hardware step by step so that a thorough understanding of the hardware is gained. In addition, the instruction set and the mechanics of programming are detailed to allow the user to program the computer. This is to assist the user in obtaining a working knowledge of both the hardware and software.

This book may be used in one of three manners. First, it can be used as a general reference book, to obtain general information. Second, it may be used as an aid to the designing and building of a computer. Third, and most important, it may be used as a guidebook to build and program the computer described here.

Charles K. Adams

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Chapter 1
Introduction

The early electronic computers, built in the late 1940's and early 1950's, were monsters created by research and development laboratories, and by the large universities. These computers required several cabinets of equipment, several people to maintain and operate them, a lot of air conditioning to keep them cool, and a lot of power to keep them running. Costing several hundred-thousand dollars, they were affordable only by the government, large corporations, and universities. These computers could perform complex mathematical operations which required many man hours to solve manually.

An increase in reliability and operating time, along with the decreasing costs, brought large computers to the commercial market. Companies came into existence solely to lease computers, or sell computer time to users. Such services increased the commercial world's exposure to the compuuter, and it soon became apparent that the computer could do several things better and faster than its human counterpart.

COMPUTERS GET A JOB

It wasn't long before companies began transferring billing and accounting to tasks to computers—the public started getting computerized bills. This introduced the public to the computer; and the public soon found out that the computer does only what it is told.

The early computers fulfilled their obligation—the handling and sorting of large amounts of data— but in turn created another requirement. Business required a small, inexpensive computer that was simple to program and operate. Such a computer was needed to replace the increasingly complex logic arrays required in some of the current logic designs.

It was the advent of a microprocessor— the heart of the microcomputer — that changed things. That this computer is simple, inexpensive, and easy to use, is proven by its tremendous popularity. There are thousands of hobbyists making, programming, and using microcomputers in addition to the millions in use in the commercial world. Microcomputers now control almost everything from toys to automobile-combustion efficiency. From games to microwave ovens. From stop lights to numerically controlled machines.

The microcomputer boom is just beginning. Advances in the microcomputer area almost daily. There is even a microcomputer which operates on analog inputs or outputs, along with the digital functions. Large quantities of preprogrammed single—chip microcomputers are available which cost less than $10 each (in volumes of several thousand).

The advent of semiconductor theory and solid-state technology led to the development of the transistor. This device virtually replaced the vacuum tube for a large percentage of electronic applications. The transistor led to such things as the transistor radio, stereos, and the cassette recorder.

Manufacturing techniques that were developed to make the transistor, along with an increase in knowledge about solid-state theory and semiconductor applications led to the development of the digital integrated circuit (IC). The IC comprised several transistors, diodes and other components on one small piece of semiconductor material. This piece of semiconductor material (the chip) was encapulsated into a package with leads. Such simple digital ICs each replaced several discrete components.

MAKING COMPUTERS EVEN SMALLER

Improvements to process techniques and the development of photographic reduction processes and equipment led to increasingly complex circuits in the ICs. This led to medium-scale integration (MSI) and eventually to large-scale integration (LSI); more and more components were incorporated into one IC. A typical LSI circuit requires about 7 masks for its deposition and doping operations. The photographic masker, from which the masks are made, is 200 times real size, and may be 10 to 20 feet square. This is the technology that generated the microprocessor. Now there are third and fourth generation devices available, which obsolete the early devices. The new devices can equal 450 standard digital ICs (or 110 MSI devices), and yet come in a standard 40 pin dual in line package (DIP). Most of their area is devoted to connecting the chip to the package pins for connection to the outside world.

Processor	Number of pins	Data word size	Addressing capability	Number of instructions
4004	16	4 bits	4K bytes	46
4040	24	4	8K	60
8000	40	8	1K	48
8008	18	8	16K	48
8080	40	8	64K	78
6800	40	8	64K	72
2650	40	8	32K	75
Z80	40	8	64K	150
6100	40	12	4K	81
9440	40	16	64K	42
8086	40	16	1M	97
68000	64	16	16M	61

Fig. 1-1. Comparison of some of the popular microprocessors.

There are several microprocessors available. These range from simple 4-bit devices to complex 16-bit devices. Some of the devices contain all that is required for a small, simple computer. Figure 1-1 shows the sizes of some of these devices, and lists some of their important characteristics.

As the microcomputer becomes more versatile and capable of doing more things, the line differentiating a minicomputer from a microcomputer becomes fuzzier—their applications and capabilities overlap. The microcomputer is usually defined as a computer with a single-chip central processor unit (CPU); the minicomputer covered the range from the simple-computer applications to those of the large computers before the days of the microcomputer.

Figure 1-2 shows the block diagram of a test set that detects opens in cords for a production-repair facility. The computer used to control the test set has a program of less than 500 words, and a temporary memory of 256 words. Yet it controls several analog switches and provides several LED indications of the cord's status. This is the first of many computers that the author built. It is a small computer, and could today be replaced by a single-chip computer, cutting the required number of circuit boards from two to one.

HOW TO USE THIS BOOK

That's what this book is all about — building, testing, and programming a simple microcomputer. This microcomputer is a small device, with 1k of temporary RAM and up to 3k of permanent memory. But you can expand it up to 8k of memory. Hardware read and load, and single step circuitry assist in troubleshooting and bringing the system up. Keyboard read load, and a 7-segment display allow the operator to talk with the computer. An EPROM programmer is included to allow the operator to commit programs to permanent memory.

The individual computer sections are explained in an effort to acquaint the reader with the hardware which makes up the system. To efficiently utilize a microcomputer, both

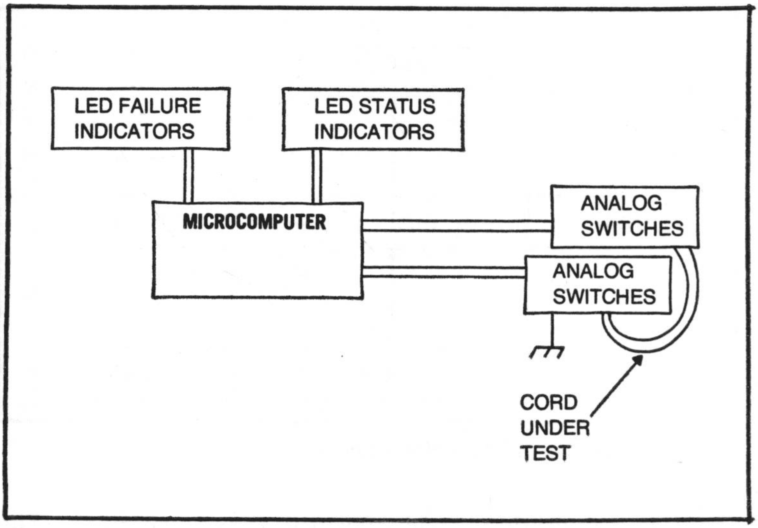

Fig. 1-2. Block diagram for a microcomputer-controlled test set that tests four-conductor cords.

its hardware operation and programming must be known and understood. The instruction set is present along with the steps required to write programs. Then come some actual programs for the reader to run in the computer. By that time the reader will have acquired enough knowledge and experience to write programs and program the computer. This step-by-step process allows exploiting the computer's capability as desired. The applications for microcomputers are limited only by the ingenuity of the reader.

COMPUTER BUILDING BLOCKS

Figure 1-3 illustrates a typical computer's simplified block diagram. All computers comprise these basic blocks; the size of the computer is determined by how much is in the basic blocks. Large computers have a larger CCU, larger memory, and more and different input and output devices. The basic blocks include:

Central control unit. The central control unit (CCU), sometimes called the central processor unit (CPU), forms the central part of the computer. It is the brains of the system; it decodes the instructions, performs the arithmetic

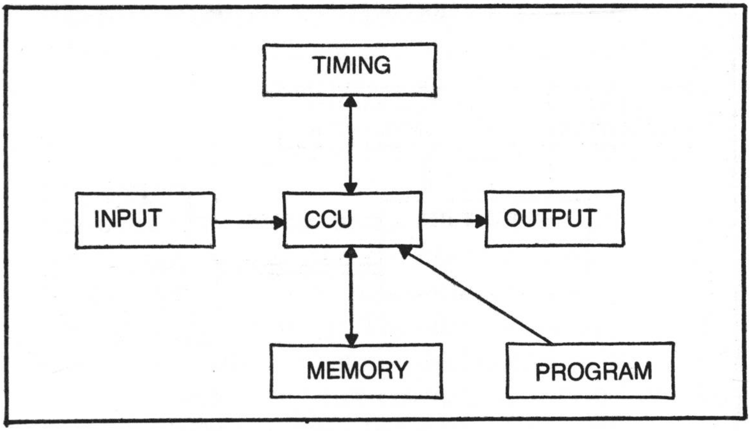

Fig. 1-3. Block diagram of a typical computer.

and logic operations, and executes the instructions. The program counter in the CCU keeps track of the address of the next instruction to be executed.

Memory. The memory stores programs, data, and program variables. The memory used by microcomputers is usually a semiconductor memory, and comprises both permanent and temporary memory. Random-access memories (RAM) furnish temporary storage. The computer writes into them and reads from them but the information is lost when the computer is powered down, whether intentionally or accidentally.

Erasable Programmable Read-Only Memories (EPROM's). These are permanent semiconductor memories. They can be erased with an ultraviolet lamp, and programmed using a programming circuit (PROM programmer). Their contents can't be altered under program control during normal computer operation, and are not lost when the computer is powered down.

Some computers, microcomputers included, use some type of mass storage to store data, programs, and information. This mass storage device may be a cassette recorder, special tape units, or disk units. These store large amounts of data, and many programs, which can be read into the computer one section at a time.

Input/output. The input and output devices allow communication between the computer and the outside world. For a general-purpose computer, the input may be a keyboard, terminal, or tape unit. The output may be a printer, display, or graphics plotter. For specialized machines, the input may be a position code, flow meter, cash register keys, or another computer. The output device may be a stepping motor, gas pump display, printer, or other control device (Figs. 1-4 and 1-5).

Timing. Ensuring that the total computer operates with everything in step requires timing circuitry. This timing circuitry provides the timing and control signals required for the computer to operate and execute instructions.

Program. The program (software) is just as important as the computer's hardware. The program comprises a series of instructions which the computer hardware executes to accomplish a desired task. Programs come in all shapes and sizes, and each programmer programs in a slightly different manner.

For a program to operate the hardware, the CPU reads the program one instruction at a time. Each instruction consists of a unique set of ONEs and ZEROs, which, when read into the computer at the proper time, decode as the commands that enable specific logic circuits within the mi-

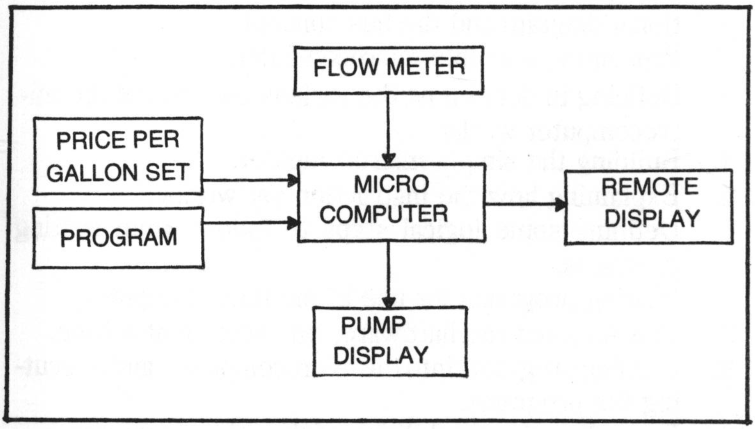

Fig. 1-4. Block diagram of a microcomputer-controlled gasoline pump.

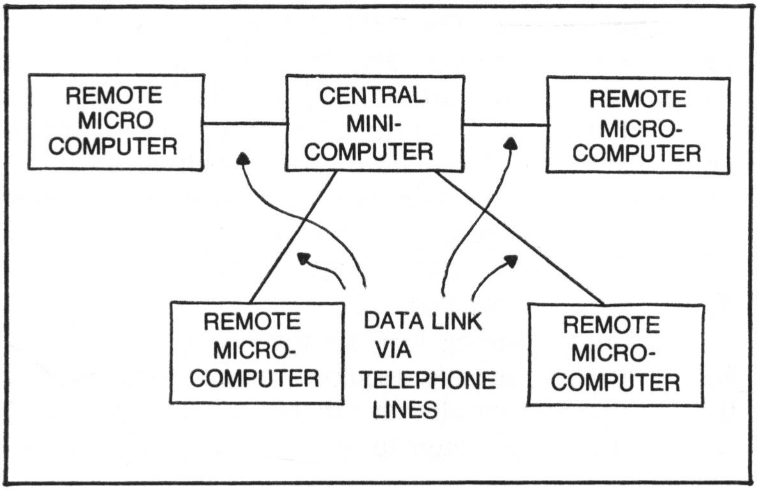

Fig. 1-5. Block diagram of a computerized test network using a centralized minicomputer connected to microcomputer-controlled test sets via a data link.

croprocessor to execute the instruction. In another time frame the same set of ONEs and ZEROs might be decoded as data.

As previously alluded to, the objective of this book is to introduce the reader to a microcomputer, to present and discuss the hardware, build a microcomputer, learn the instruction set, and program the computer. This is done in the following steps:

1. Introduction to the microcomputer through the functional diagram and the bus concept.
2. Presenting a simple microcomputer.
3. Defining in detail how the various sections of the microcomputer works.
4. Building the simple microcomputer.
5. Explaining how the instruction set works.
6. Defining some logical steps to follow when writing programs.
7. Writing programs for use in the microcomputer.
8. Checking out the hardware, one section at a time.
9. Loading programs into the microcomputer, and executing the programs.
10. Expanding the capabilities of the microcomputer.