Build a Z8-Based Control Computer with BASIC, Part 1

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I hope you believe me when I say that I have been waiting years to present this project. For what has seemed an eternity, I have wanted a microcomputer with a specific combination of capabilities. Ideally, it should be inexpensive enough to dedicate to a specific application, intelligent enough to be programmed directly in a high-level language, and efficient enough to be battery operated.

My reason for wanting this is purely selfish. The interfaces I present each month are the result of an overzealous desire to control the world. In lieu of that goal, and more in line with BYTE policy, I satisfy this urge by stringing wires all over my house and computerizing things like my wood stove.

There are many more places I'd like to apply computer monitoring and control. I want to modify my home-security system to use low-cost *distributed* control rather than central control. I want to try my hand at a little energy management, and, of course, I am still trying to find some reason to install a microcomputer in a car. (How about a talking dashboard?)

Generally, the projects I present each month are designed to be attached to many different commercially available microcomputers through existing I/O (input/output) ports. Most of my projects are applicable for use on the small (by IBM standards) computers owned by many readers, but, unfortunately, a typical home-computer system cannot be stuffed under a car seat.

The Z8-BASIC Microcomputer is a milestone in low-cost microcomputer capability.

The time has come to present a versatile "Circuit Cellar Controller" board for some of these more ambitious control projects. I decided not to adapt an existing single-board computer, which would be larger, more expensive, and generally limited to machine-language programming. Instead, I started from scratch and built exactly what I wanted.

The microcomputer/controller I developed is called the Z8-BASIC Microcomputer. Its design and application will be presented in a two-part article beginning this month. In my opinion, it is a milestone in low-cost microcomputer capability. It can be utilized as an inexpensive tiny-BASIC computer for a variety of changing applications, or it can be dedicated to specialized tasks, such as security control, energy management, solar-heating-system monitoring, or intelligent-peripheral control. [**Editor's Note:** *We are using the term "tiny BASIC" generically to denote a small, limited BASIC interpreter. The term has been used to refer to some specific commercially available products based on the Tiny BASIC concept promulgated by the People's Computer Company in 1975....***RSS**]

The entire computer is slightly larger than a 3 by 5 file card, yet it includes a tiny-BASIC interpreter, 4 K bytes of program memory, one RS-232C serial port and two parallel I/O ports, plus a variety of other features. (A condensed functional specification is shown in the "At a Glance" text box.) Using a Zilog Z8 microcomputer integrated circuit and Z6132 4 K by 8-bit read/write memory device, the Z8-BASIC Microcomputer circuit board is completely self-contained and optimized for use as a dedicated controller.

To program it for a dedicated application, you merely attach a user terminal to the DB-25 RS-232C connector, turn the system on, and type in a BASIC program using keywords such as GOTO, IF, GOSUB, and LET. Execution of the program is started by typing RUN. If you need higher speed than BASIC provides, or if you just want to experiment with the Z8 instruction set, you can use the

GO@ and USR keywords to call machine-language subroutines.

Once the application program has been written and tested with the aid of the terminal, the finished program can be transferred to an EPROM (erasable programmable read-only memory) via a memory-dump program and the terminal disconnected. Next, the 28-pin Z6132 memory component is removed from its socket and either a type-2716 (2 K by 8-bit) or type-2732 (4 K by 8-bit) EPROM is plugged into the lower 24 pins. (The choice of EPROM depends upon the length of the program.) When the Z8 board is powered up, the stored program is immediately executed. *The EPROM devices and the Z6132 read/write memory device are pin-compatible.* Permanent program storage is simply a matter of plugging an EPROM into the Z6132's socket.

There is much more power on this board than is alluded to in this simple description. That is why I decided to use a two-part article to explain it. This month, I'll discuss the design of the system and the attributes of the Z8 and Z6132. Next month, I'll describe external interfacing techniques, a few applications, and the steps involved in transferring a program into an EPROM.

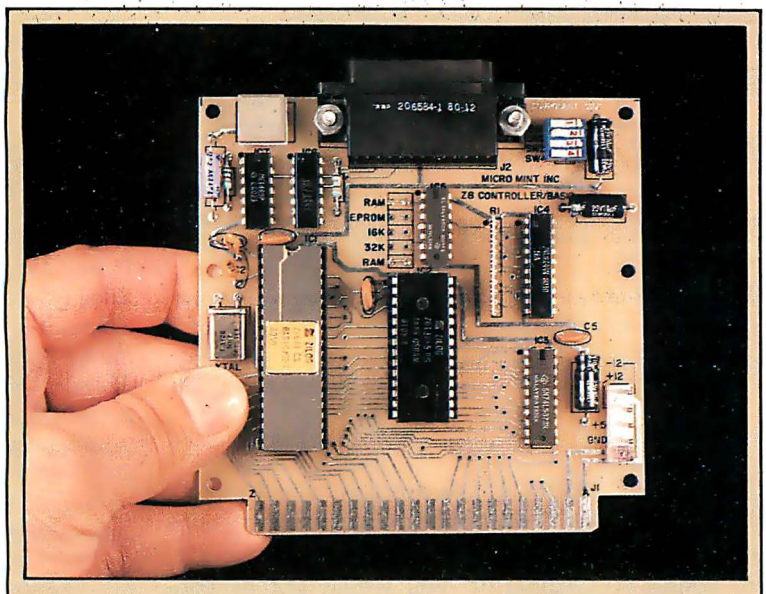

Photo 1: *A prototype of the versatile "Circuit Cellar Controller," formally called the Z8-BASIC Microcomputer. The printed-circuit board measures 4 by 4½ inches and has a 44-pin (two-sided 22-pin) edge connector with contacts on 0.156-inch centers. A 2716 or 2732 EPROM can be substituted for the Z6132 Quasi-Static memory, plugging into the same socket.*

Single-Chip Microcomputers

The central component in the Z8-BASIC Microcomputer is a member of the Zilog Z8 family of devices. The specific component used, the Z8671, is just one of them. Unlike a micro*processor*, such as the well-known Zilog Z80, the Z8 is a single-chip micro*computer*. It contains programmable (read/write) memory, read-only memory, and I/O-control circuits, as well as circuits to perform standard processor functions. Microprocessors such as the Z80 or the Intel 8080 require support circuitry to make a functional computer system. A single-chip microcomputer, on the other hand, can function solely on its own.

The concept is not new. Single-chip microcomputers have been around for quite a while, and millions of them are used in electronic games. The designers of the Z8, however, raised the capabilities of single-chip microcomputers to new heights and provided many powerful features usually found only in general-application microprocessors.

Typically, single-chip microcomputers have been designed for microcontroller applications and optimized for I/O processing. On a 40-pin dual-inline package, as many as 32 of the pins can be I/O related. A ROM-programmed single-chip microcomputer used in an electronic chess game might offer a thousand variations in game tactics, but it could not be reprogrammed as a word processor. The ability to reorient processing functions and reallocate memory has generally been the province of microprocessors, with their memory-intensive architecture.

The Z8 architecture (shown in figure 1a on page 40) allows it to serve in either memory- or I/O-intensive applications. Under program control, the Z8 can be configured as a stand-alone microcomputer using 2 K to 4 K bytes of internal ROM, as a traditional microprocessor with as much as 120 K to 124 K bytes of external memory, or as a parallel-processing unit working with other computers. The Z8 could be used as a controller in a microwave oven or as the processor in a stand-alone data-entry terminal complete with floppy-disk drives.

Getting Specific: The Z8671

The member of the Z8 family used in this project is the Z8671. This component differs from the garden-variety Z8601 chiefly in the contents of the ROM set at the factory. The pinout specification of the Z8671 is shown in figure 1b, and the package is shown in photo 2 on page 41. The Z8671 package contains the processor circuitry, 2 K bytes of ROM (preprogrammed with a tiny-BASIC interpreter and a debugging monitor), 32 I/O lines, and 144 bytes of programmable (read/write) memory.

The operational arrangement of memory-address space is shown in figure 1c. The internal read/write memory is actually a register file (illustrated in figure 2) composed of 124 general-purpose registers (R4 thru R127), 16 status-control registers (R240 thru R255), and 4 I/O-port registers (R0 thru R3). Any general-purpose register can be used as an accumulator, address pointer, index register, or as part of the internal stack area. The significance of these registers will be explained when I describe the tiny-BASIC/Debug interpreter/monitor.

The 32 I/O lines are grouped into four separate ports and treated internally as 4 registers. They can be configured by software for either input or output and are compatible with

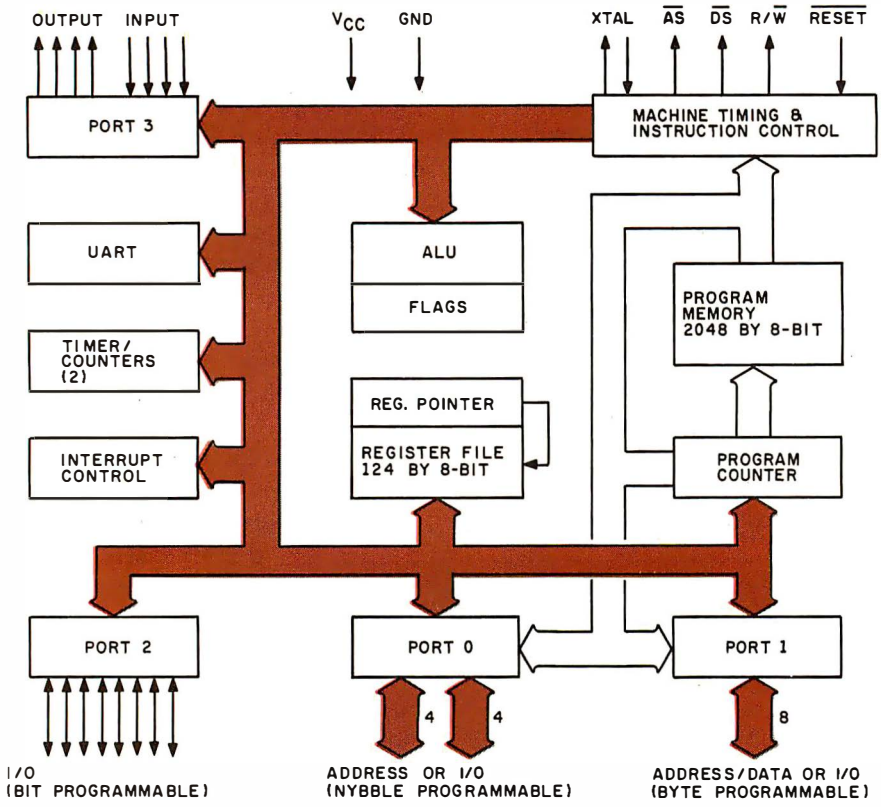

Figure 1a: *Block diagram of the Zilog Z8-family single-chip microcomputers. Their architecture allows these devices to serve in either memory- or I/O-intensive applications. This figure and figures 1b, 1c, 2, 3, and 4 were provided through the courtesy of Zilog Inc.*

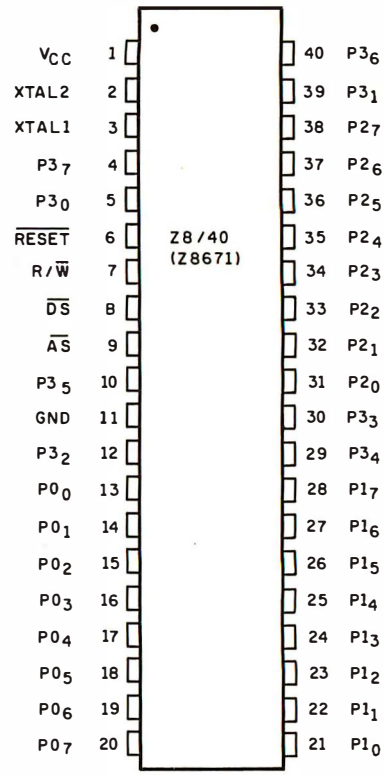

Figure 1b: *Pinout specification of the Zilog Z8671 microcomputer. The Z8671 is a variant of the basic Z8601 component of the Z8 family. The Z8671 is used in this project because it contains the BASIC/Debug interpreter/monitor in read-only memory. Other members of the Z8 family are supplied in different packages, chiefly to support system-development work.*

LSTTL (low-power Schottky transistor-transistor logic). In addition, port 1 and port 0 can serve as a multiplexed address/data bus for connection of external memory and peripheral devices.

In traditional nomenclature, port 1 transceives the data-bus lines D0 thru D7 and transmits the low-order address-bus signals A0 thru A7. Port 0 supplies the remaining high-order address lines A8 thru A15, for a total of 16 address bits. This allows 62 K bytes of *program* memory (plus 2 K bytes of ROM) to be directly addressed. If more memory is required, one bit in port 3 can be set to select another memory bank of 62 K bytes, which is referred to as *data* memory. In the Z8-BASIC Microcomputer presented here, a separate data-memory bank is not implemented, and program and data memory are considered to be the same.

The Z8 has forty-seven instructions, nine addressing modes, and six interrupts. Using a 7.3728 MHz crystal (producing a system clock rate of 3.6864 MHz) most instructions take about 1.5 to 2.5 μs to execute. Ordinarily, you would not be concerned about single-chip-microcomputer instruction sets and interrupt handling because the programs are mask-programmed into the ROM at the factory. In the Z8671, however, only the BASIC/Debug interpreter is preprogrammed. Using this interpreter, you can write machine-language programs that can be executed through subroutine calls written in BASIC. This feature greatly enhances the capabilities of this tiny computer and potentially allows the software to control high-speed peripheral devices. (A complete discussion of the Z8 instruction set and interrupt structure is beyond the scope of this article. The documentation accompanying the Z8-BASIC Microcomputer Board describes the instruction set in detail.)

The final area of concern is communication. The Z8 contains a full-duplex UART (universal asynchronous receiver/transmitter) and two counter/timers with prescalers. One of the counters divides the 7.3728 MHz crystal frequency to one of eight standard data rates. With the Z8671, these rates range between 110 and 9600 bps (bits per second) and are switch- or software-selectable.

A block diagram of the serial-I/O section is shown in figure 3. Serial data is received through bit 0 of port 3 and transmitted from bit 7 of port 3. While the Z8 can be set to transmit odd parity, the Z8671 is preset for 1 start bit, 8 data bits, no parity, and 2 stop bits. Received data must have 1 start bit, 8 data bits, at least 1 stop bit, and no parity (in this configuration).

Quasi-Static Memory

A limiting factor in small controller

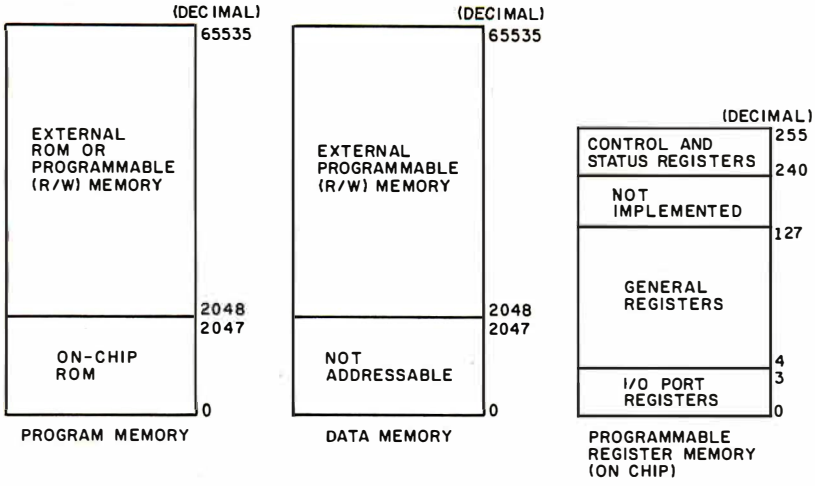

Figure 1c: *The operational arrangement of memory-address space in the Z8 family. The regions labeled "program memory" and "data memory" may map to the same physical memory, or two separate banks may be used, selected through one bit of I/O port 3. The internal programmable (read/write) memory is a register file containing 124 general-purpose registers, 16 status-control registers, and 4 I/O-port registers.*

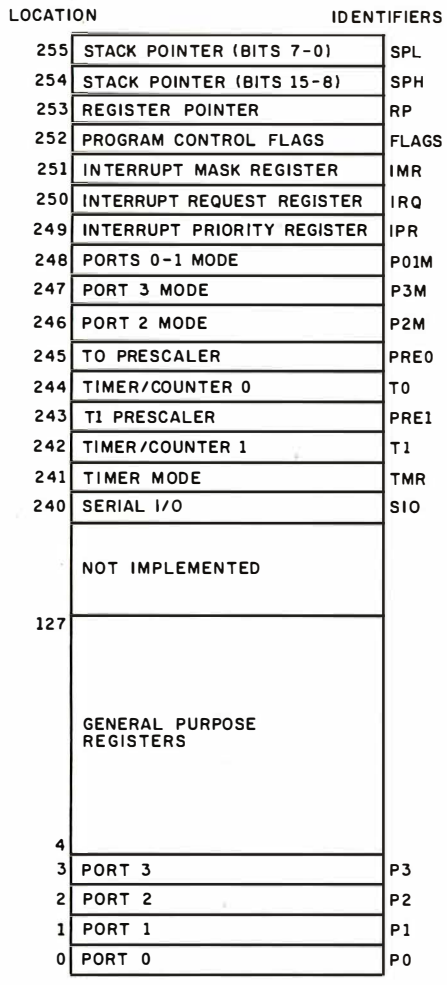

Figure 2: *An expanded view of the register-memory section of figure 1c, showing the organization of the register file. Any general-purpose register can be used as an accumulator, address pointer, index register, or as part of the internal stack area.*

designs has always been the trade-off between memory size and power consumption. To keep the number of components down and simplify construction, a designer generally selects a limited quantity of static memory. Frequently, the choice is to use two type-2114 1 K by 4 NMOS (negative-channel metal-oxide semiconductor) static-memory devices. In practice, however, the 1 K-byte memory size thereby provided is rather limited. It would be much better to expand this to at least 4 K bytes. Unfortunately, eight 2114 chips require considerably more circuit-board space and consume about 0.7 amps at +5 V. Not only would this make the design ill suited for battery power, it could never fit on my 4- by 4½-inch circuit board.

Another approach is to use dynamic memory, as in larger computers. Dynamic memory costs less, bit for bit, than static memory and consumes little power. Unfortunately, most dynamic-memory components require three separate operating voltages and special refresh circuitry. Adding 4 K bytes of dynamic memory would probably take about twelve chips. The advantages gained in reduced power consumption hardly justify the expense and effort.

The solution to this problem, surprisingly enough, also comes from Zilog, in the form of the Z6132 Quasi-Static Memory. The Z6132, shown in photo 4 on page 43, is a 32 K-bit dynamic-memory device, organized into 4 K 8-bit (byte-size) words. It uses single-transistor dynamic bit-storage cells, but the device performs and controls its own data-refresh operations in a manner that is completely invisible to the user and the rest of the system. This eliminates the need for external refresh circuitry. Also, the Z6132 requires only a +5 V power supply. The result is a combination of the design convenience of static memory and the low power consumption of dynamic memory. All 4 K bytes of memory fit in a single 28-pin dual-in-line package, which typically draws about 30 milliamps.

An additional benefit in using the Z6132 is that it is pin-compatible with standard type-2716 (2 K by 8-bit) and type-2732 (4 K by 8-bit) EPROMs. This feature is extremely beneficial when you are configuring this Z8 board for use as a dedicated controller. As previously mentioned, the Z6132 can be removed and an EPROM inserted in the low-order 24 pins of the same socket. Thus, any program written and operating in the Z6132 memory can be placed in a

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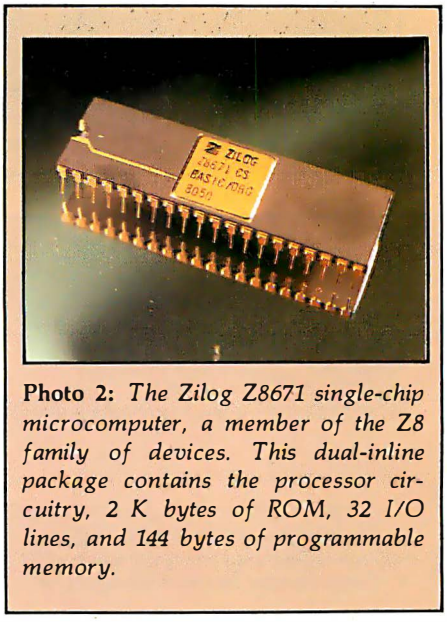

Photo 2: *The Zilog Z8671 single-chip microcomputer, a member of the Z8 family of devices. This dual-inline package contains the processor circuitry, 2 K bytes of ROM, 32 I/O lines, and 144 bytes of programmable memory.*

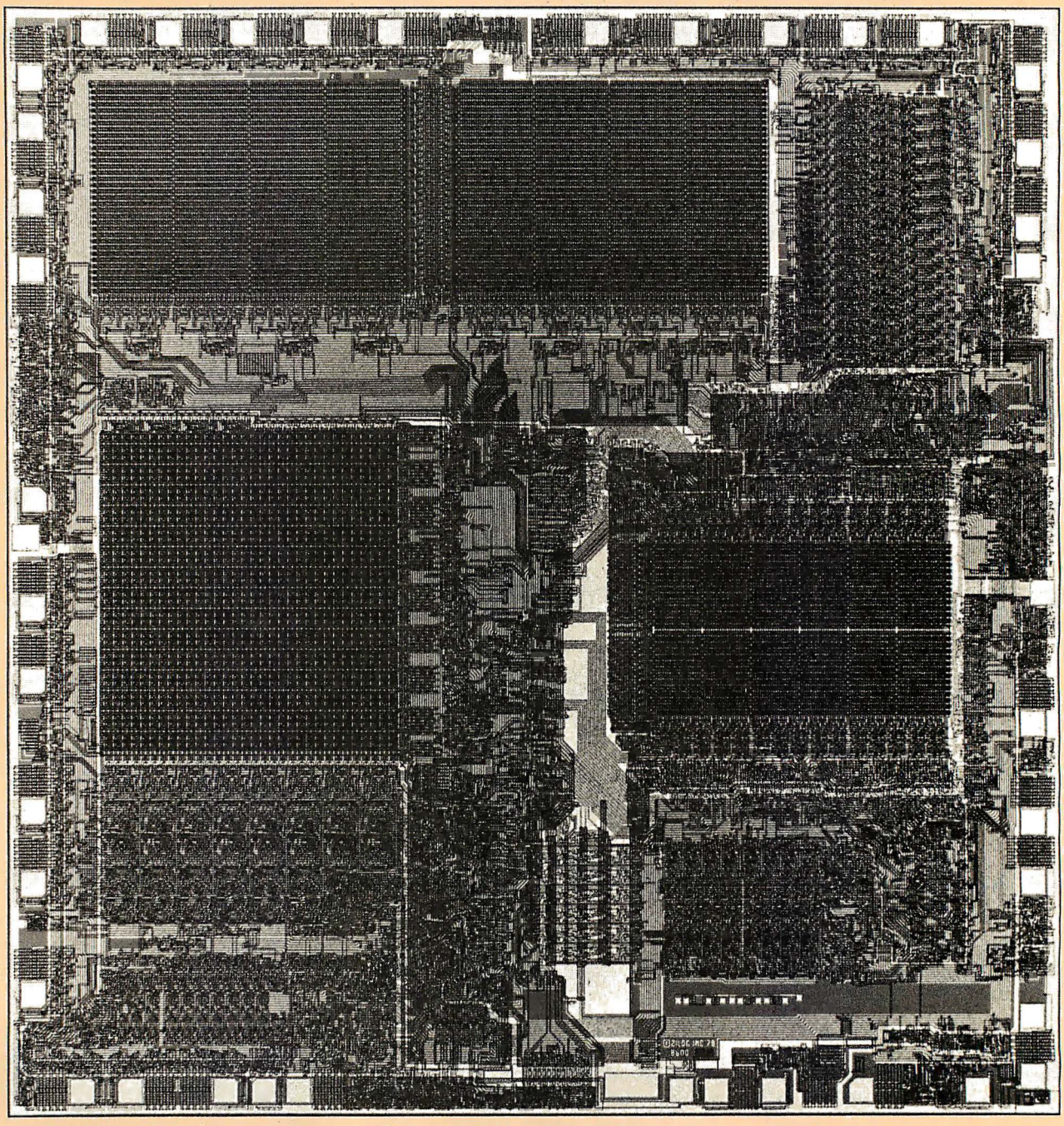

Photo 3: *A photomicrograph of the silicon chip containing the working parts of a Z8 microcomputer.*

The following items are available from:
The MicroMint Inc
917 Midway
Woodmere NY 11598
Telephone:
(800) 645-3479 (for orders)
(516) 374-6793 (for technical information)

Z8-BASIC Microcomputer
Documentation includes:
Z8 Technical Manual, Z8 Product Specification
Z6132 Product Specification
BASIC/Debug Manual
Z8-BASIC Microcomputer Construction/Operator's Manual
Assembled and tested....$170
Kit....$140

Z8-BASIC Microcomputer power supply
(Size: 2⅛ by 4½ inches)
Provides: +5 V, 300 mA
+12 V, 50 mA
−12 V, 50 mA
Assembled and tested....$35
Kit....$27

All printed-circuit boards are solder-masked and silk-screened.
The documentation supplied with the Z8 board includes approximately 200 pages of materials. It is available separately for $25. This charge will be credited toward any subsequent purchase of the Z8 board.
Please include $4 for shipping and handling. New York residents please include 7% sales tax.

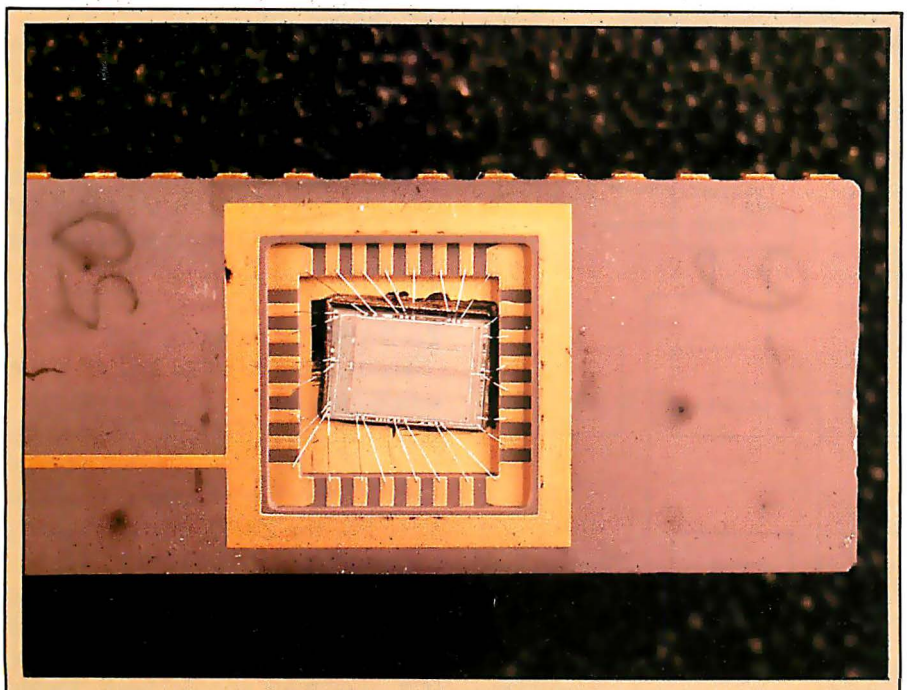

Photo 4: *The Zilog Z6132 Quasi-Static Memory device, shown with the hood up. This component stores 32 K bits in the form of 4 K bytes in invisibly refreshed dynamic-memory cells.*

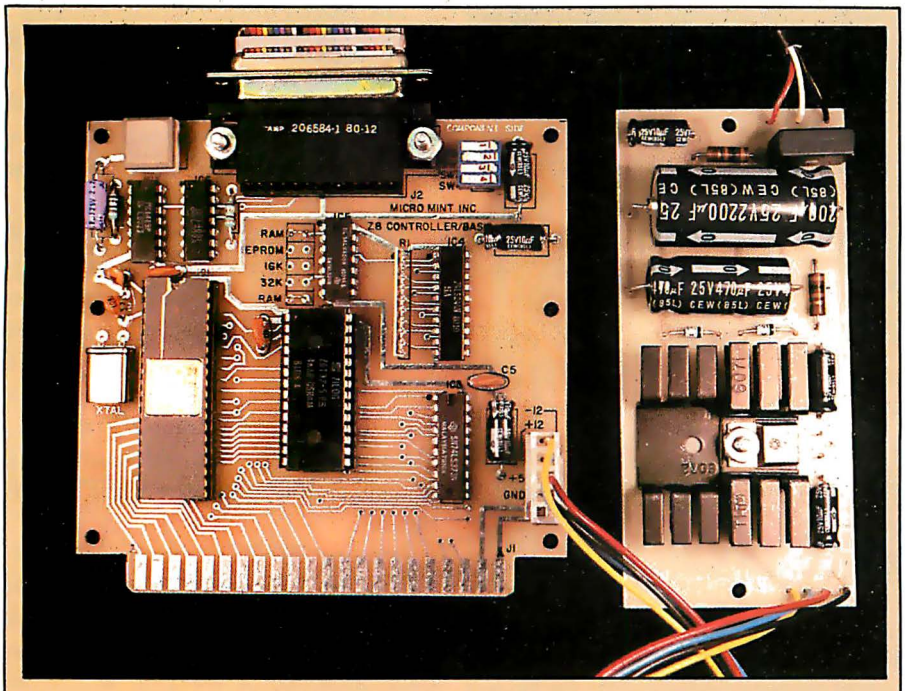

Photo 5: *The Z8-BASIC Microcomputer Board attached to a power supply. Power can be supplied either through the separate power connector, as shown, or through the edge connector.*

At a Glance

Name
Z8-BASIC Microcomputer

Processor
Zilog Z8-family Z8671 8-bit microcomputer with programmable (read/write) memory, read-only memory, and I/O in a single package. The Z8671 includes a 2 K-byte tiny-BASIC/Debug resident interpreter in ROM, 144 bytes of scratch-pad memory, and 32 I/O lines. System uses 7.3728 MHz crystal to establish clock rate. Two internal and four external interrupts.

Memory
Uses Z6132 4 K-byte Quasi-Static Memory (pin-compatible with 2716 and 2732 EPROMs); 2 K-byte ROM in Z8671. Memory externally expandable to 62 K bytes of program memory and 62 K bytes of data memory.

Input/Output
Serial port: RS-232C-compatible and switch-selectable to 110, 150, 300, 1200, 2400, 4800, and 9600 bps.
Parallel I/O: two parallel ports; one dedicated to input, the other bit-programmable as input or output; programmable interrupt and handshaking lines; LSTTL-compatible.
External I/O: 16-bit address and 8-bit bidirectional data bus brought out to expansion connector.

BASIC Keywords
GOTO, GO@, USR, GOSUB, IF...THEN, INPUT, LET, LIST, NEW, REM, RETURN, RUN, STOP, IN, PRINT, PRINT HEX. Integer arithmetic/logic/operators: +, −, /, *, and AND; BASIC can call machine-language subroutines for increased execution speed; allows complete memory and register interrogation and modification.

Power-Supply Requirements
+5 V ±5% at 250 mA
+12 V ±10% at 30 mA
−12 V ±10% at 30 mA
(The 12 V supplies are required only for RS-232C operation.)

Dimensions and Connections
4- by 4½-inch board; dual 22-pin (0.156-inch) edge connector. 25-pin RS-232C female D-subminiature (DB-25S) connector; 4-pole DIP-switch data-rate selector.

Operating Conditions
Temperature: 0 to 50°C (32 to 122°F)
Humidity: 10 to 90% relative humidity (noncondensing)

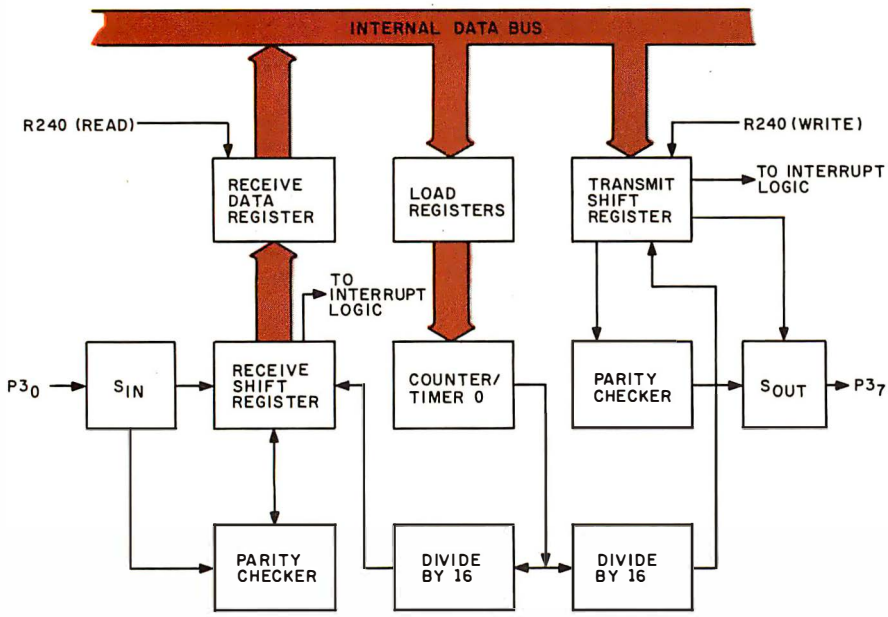

Figure 3: *Block diagram of the serial-I/O section of the Z8-family microcomputers. The Z8 contains a full-duplex UART (universal asynchronous receiver/transmitter). The data rates are derived from the clock-rate crystal frequency. Serial data is received through bit 0 of port 3 and is transmitted from bit 7 of port 3. An interrupt is generated within the Z8 whenever transmission or reception of a character has been completed.*

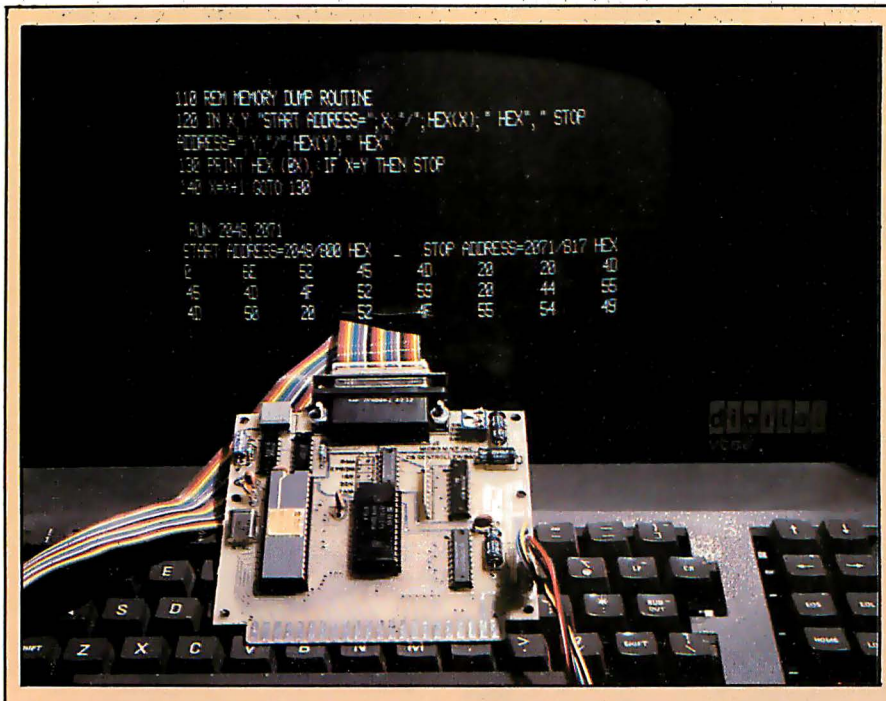

Photo 6: *The Z8-BASIC Microcomputer in operation, communicating with a video terminal (here, a Digital Equipment Corporation VT8E). A memory-dump routine, written using the BASIC/Debug interpreter, is shown on the display screen. The starting address of the dump is the beginning of the user-memory area; the hexadecimal values displayed are the ASCII (American Standard Code for Information Interchange) values of the characters that make up the first line of the memory-dump program.*

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nonvolatile EPROM. (There are some limitations placed on the number of subroutine calls and variables allowed by this substitution because variable data and return addresses must be stored in the Z8's register area instead of in external read/write memory.)

Z8-BASIC Microcomputer

Figure 5 on pages 46 and 47 is the schematic diagram of the seven-integrated-circuit Z8-BASIC Microcomputer Board, shown in prototype form, with a power supply, in photo 5. IC1 is the Z8671 microcomputer, the member of the Z8 family that contains Zilog's 2 K-byte BASIC/Debug software in read-only memory. IC2 is the Z6132 Quasi-Static Memory, and IC3 is an 8-bit address latch. Under ordinary circumstances, the Z6132 is capable of latching its address internally, but IC3 is included to allow EPROM operation. IC4 and IC5 form a hard-wired memory-mapped input port used to read the data-rate-selection switches. IC6 and IC7 provide proper voltage-level conversion for RS-232C serial communication.

The seven-integrated-circuit computer typically takes about 200 milliamps at +5 V. The +12 V and −12 V supplies are required only for operating the RS-232C interface. Power required is typically about 25 milliamps on each.

The easiest way to check out the Z8-BASIC Microcomputer after assembly is to attach a user terminal to the RS-232C connector (J2) and set the data-rate-selector switches to a convenient rate. I generally select 1200 bps, with SW2 closed and SW1, SW3, and SW4 open. After applying power, simply press the RESET push button.

Pressing RESET starts the Z8's initialization procedure. The program reads location hexadecimal FFFD in memory-address space, to which the data-rate-selector switches are wired to respond. When it has acquired this information, it sets the appropriate data rate and transmits a colon to the terminal. At this point, the Z8 board is completely operational and programs can be entered in tiny BASIC.

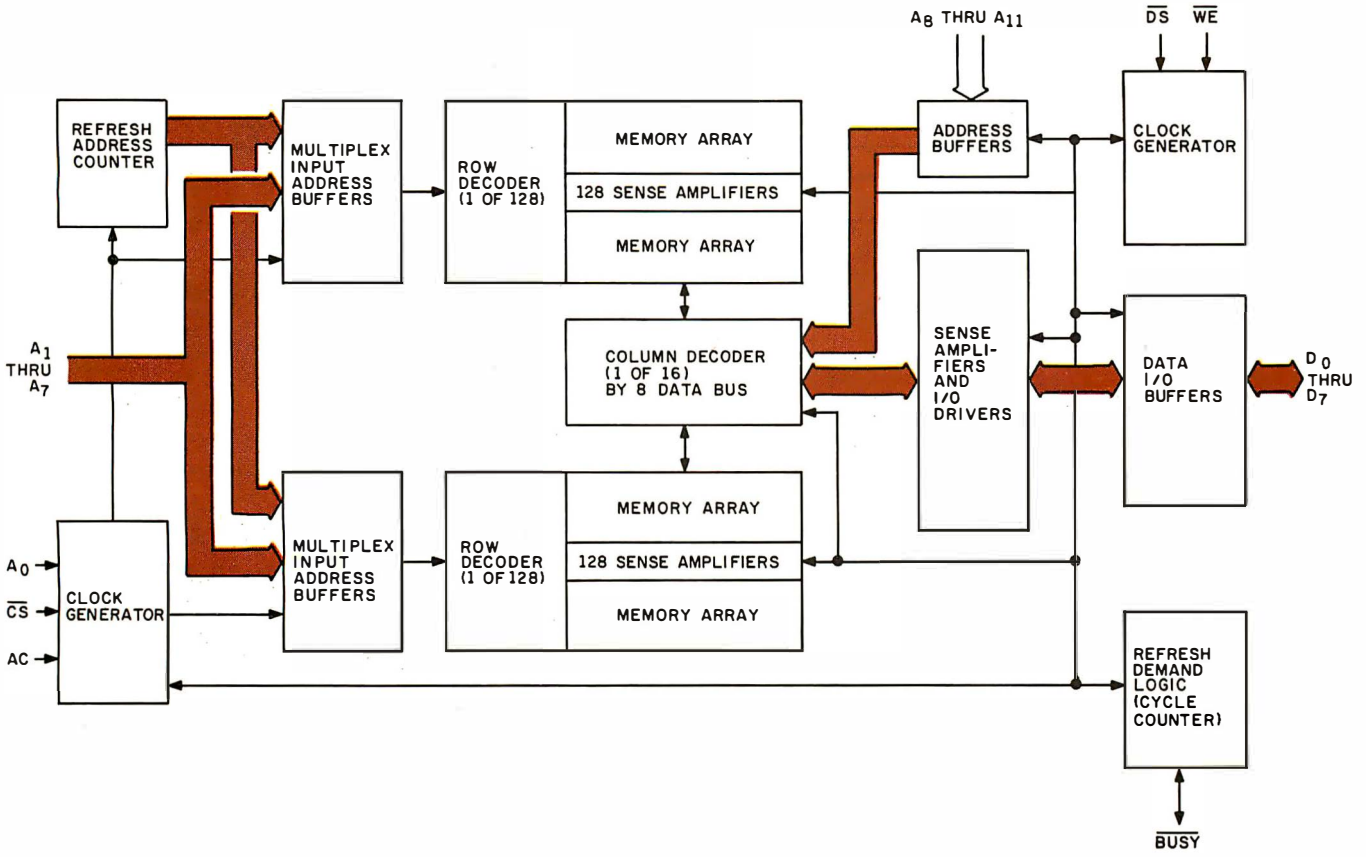


Figure 4: *Block diagram of the Zilog Z6132 Quasi-Static Memory component. This innovative part stores 32 K bits in the form of 4 K bytes, using single-transistor dynamic random-access bit-storage cells, but all refresh operations are controlled internally. The memory-refresh operation is completely invisible to the user and the other components in the system. The Z6132 draws about 30 milliamps from a single +5 V power supply.*

(With the simple address selection employed in this circuit, the data-rate switches will be read by an access to any location in the range hexadecimal C000 thru FFFF. This should not unduly restrict the versatility of the system in the type of application for which it was designed.)

BASIC/Debug Monitor

I'll go into the features of the tiny-BASIC interpreter in greater detail next month, but I'm sure you are curious about the capabilities present in a 2 K-byte BASIC system.

Essentially an integer-math dialect of BASIC, Zilog's BASIC/Debug software is specifically designed for process control. It allows examination and modification of any memory location, I/O port, or register. The interpreter processes data in both decimal and hexadecimal radices and accesses machine-language code as either a subroutine or a user-defined function.

BASIC/Debug recognizes sixteen keywords: GOTO, GO@, USR, GOSUB, IF...THEN, INPUT, IN, LET, LIST, NEW, REM, RUN, RETURN, STOP, PRINT, and PRINT HEX. Standard syntax and mathematical operators are used.

The Z8 board is not my idea of what should be available; it is available now.

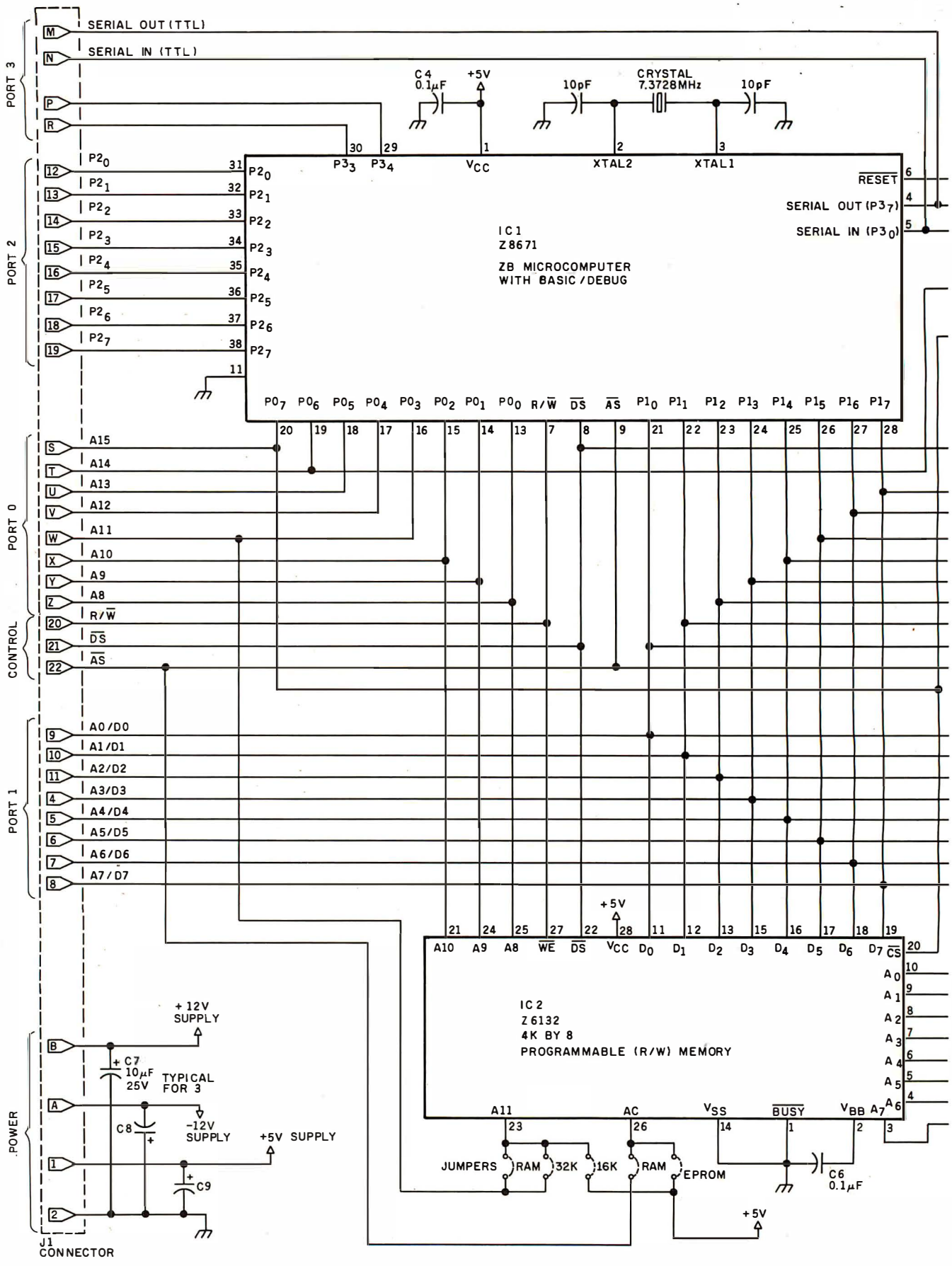
Twenty-six numeric variables, designated by the letters A thru Z, are supported. Variables can be used to designate program line numbers. For example, GOSUB B*100 and GOTO A*B*C are valid expressions.

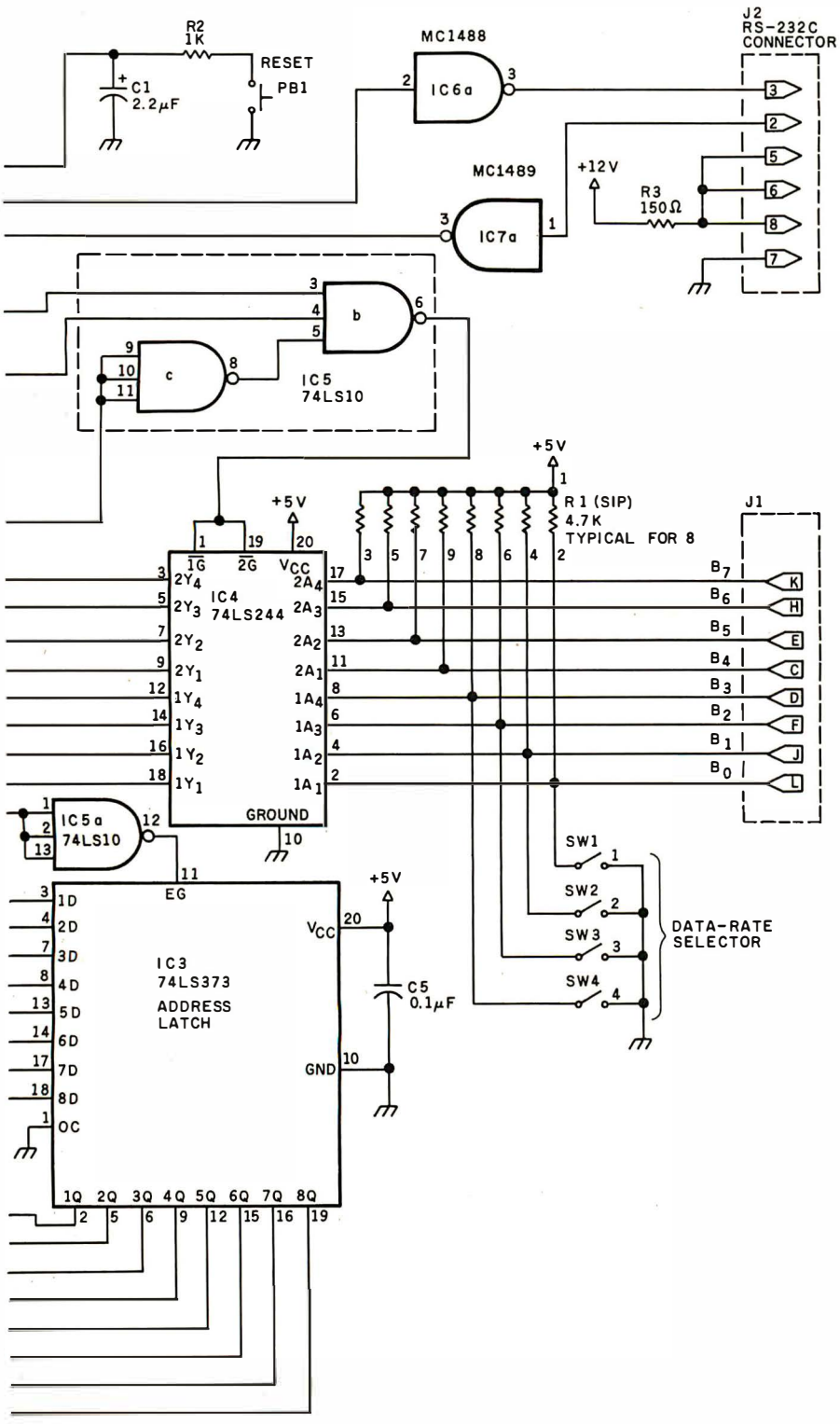
In my opinion, the 2 K-byte interpreter is extremely powerful. Because it operates easily on register and memory locations, arrays and blocks of data can be easily manipulated.

(Full appreciation of the Z8-BASIC Microcomputer comes after a complete review of the operating manuals and a little experience. Documentation approximately 200 pages long is supplied with the unit; the documentation is also available separately.)

In Conclusion

It's easy to get spoiled using a large computer as a simple control device. I have heard of many inexpensive interfaces that, when attached to any computer, supposedly perform control and monitoring miracles. Frequently overlooked, however, is the fact that implementation of these interfaces often requires the software-development tools and hardware-interfacing facilities of relatively large systems. The Z8-BASIC Microcomputer, with its interpretive language, virtually eliminates the need for costly development systems with memory-consuming text editors, assemblers, and debugging programs.


SERIAL OUT (TTL)
SERIAL IN (TTL)
PORT 3
PORT 2
PORT 0
CONTROL
PORT 1
POWER
C4 0.1μF
+5V
10pF
CRYSTAL 7.3728MHz
10pF
IC1
Z8671
ZB MICROCOMPUTER WITH BASIC/DEBUG
RESET
SERIAL OUT (P3 7)
SERIAL IN (P3 0)
XTAL2
XTAL1
VCC
P3 3
P3 4
P2 0
P2 1
P2 2
P2 3
P2 4
P2 5
P2 6
P2 7
P0 7 P0 6 P0 5 P0 4 P0 3 P0 2 P0 1 P0 0 R/W DS AS P1 0 P1 1 P1 2 P1 3 P1 4 P1 5 P1 6 P1 7
A15
A14
A13
A12
A11
A10
A9
A8
R/W
DS
AS
A0/D0
A1/D1
A2/D2
A3/D3
A4/D4
A5/D5
A6/D6
A7/D7
+5V
A10 A9 A8 WE DS VCC D0 D1 D2 D3 D4 D5 D6 D7 CS
IC2
Z6132
4K BY 8
PROGRAMMABLE (R/W) MEMORY
A0 A1 A2 A3 A4 A5 A6
A11 AC VSS BUSY VBB A7
JUMPERS
RAM
32K
16K
RAM
EPROM
C6 0.1μF
+5V
+12V SUPPLY
C7 10μF 25V
TYPICAL FOR 3
C8
-12V SUPPLY
+5V SUPPLY
C9
J1 CONNECTOR



Number	Type	+5 V	GND	−12 V	+12 V
IC1	Z8671	1	11		
IC2	Z6132	28	14		
IC3	74LS373	20	10		
IC4	74LS244	20	10		
IC5	74LS10	14	7		
IC6	MC1488		7	14	1
IC7	MC1489	14	7		

Figure 5: *Schematic diagram of the Circuit Cellar Z8-BASIC Microcomputer. Five jumper connections are provided so different memory devices can be used. For general-purpose use and program development, the 4 K-byte Z6132 read/write memory device will be used; for dedicated applications, two kinds of EPROMs can be substituted in the same integrated-circuit socket. Standard 450 ns type-2716 or type-2732 EPROM chips can be used. The connection labeled "32 K" should be closed if a type-2732 EPROM is installed; the connection labeled "16 K" should be closed for use of a type-2716 EPROM.*

The pull-up resistors adjacent to IC4 (the 74LS244 buffer) are contained in a SIP (single-inline package).

If you need a proportional motor-speed control for your solar-heating system, you don't have to dedicate your Apple II or shut off your heating system when you balance your checkbook. From now on, there is a small, cost-effective microcomputer specifically designed for such applications. The Z8 board described in this article is not my idea of what *should be* available; it *is* available now.

Next Month:

I will elaborate on interfacing and applications for the Z8-BASIC Microcomputer. ■

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Editor's Note: *Steve often refers to previous Circuit Cellar articles as reference material for the articles he presents each month. These articles are available in reprint books from BYTE Books, 70 Main St, Peterborough NH 03458.* Ciarcia's Circuit Cellar *covers articles appearing in BYTE from September 1977 thru November 1978.* Ciarcia's Circuit Cellar, Volume II *presents articles from December 1978 thru June 1980.*