New Life for the MC68HC11 Evaluation Board

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Abstract

Motorola's MC68HC11 microcontroller has been the mainstay of laboratories in introductory microprocessor courses across the country for about ten years. The Evaluation Board (EVB) for that processor has formed the basis for lab stations in most of those courses. The MC68HC11 is still probably the most popular and most capable 8-bit microcontroller in the marketplace today, so using that processor as the foundation for laboratories in microprocessor courses continues to be common.

As current lab stations age, however, lab exercises using them are becoming stale and repetitive. This paper describes a new lab station based on the MC68HC11 EVB with enhancements to support an alphanumeric keyboard, multidigit LED display, and, most interestingly, an alphanumeric CRT display that uses a standard composite video signal generated by the MC68HC11 lab station to produce a display of four rows of sixteen characters on a standard video monitor. These capabilities are achieved using a minimum of additional components added to the standard EVB. Most of the input/output (I/O) capabilities of the MC68HC11 microcontroller are employed in one way or another to implement the I/O features of this lab station. In particular, the Serial Peripheral Interface (SPI) in the MC68HC11, an I/O feature of the processor that often goes unused, is the primary means by which the video signal for the CRT monitor is generated. With both a keyboard and a CRT display directly controlled by the EVB, the need for an external terminal at the lab station is eliminated. The MC68HC11 itself can emulate a terminal through which the user interacts with a host computer for writing, assembling, and downloading programs written as student solutions to various laboratory exercises.

In this paper we describe the new lab station hardware, detailing the two additional TTL chips and handful of passive devices added to the EVB to implement the CRT video signal generation and other I/O features of the station. We also describe lab experiments and experience gained in actually using this lab station in our microprocessor class.

Introduction

This paper details a new lab station using the MC68HC11 Evaluation Board (EVB). The schematic in Figure 1 identifies the hardware to be added to the EVB to implement this lab station. This hardware includes an 8-digit 7-segment LED display, CRT display showing 4 rows of 16 alphanumeric characters, audio output, several options for use of the analog-to-digital converter, and a two-color LED for simple output indication. Also included is an alphanumeric matrix keyboard, and a 16-pin expansion connector through which an external breadboard can be interfaced using a ribbon cable to add additional capabilities for specific lab experiments. These hardware features added to the MC68HC11 EVB are detailed below, on a port-by-port basis. Most of the features of the MC68HC11 processor are used or are accessible using this lab station.
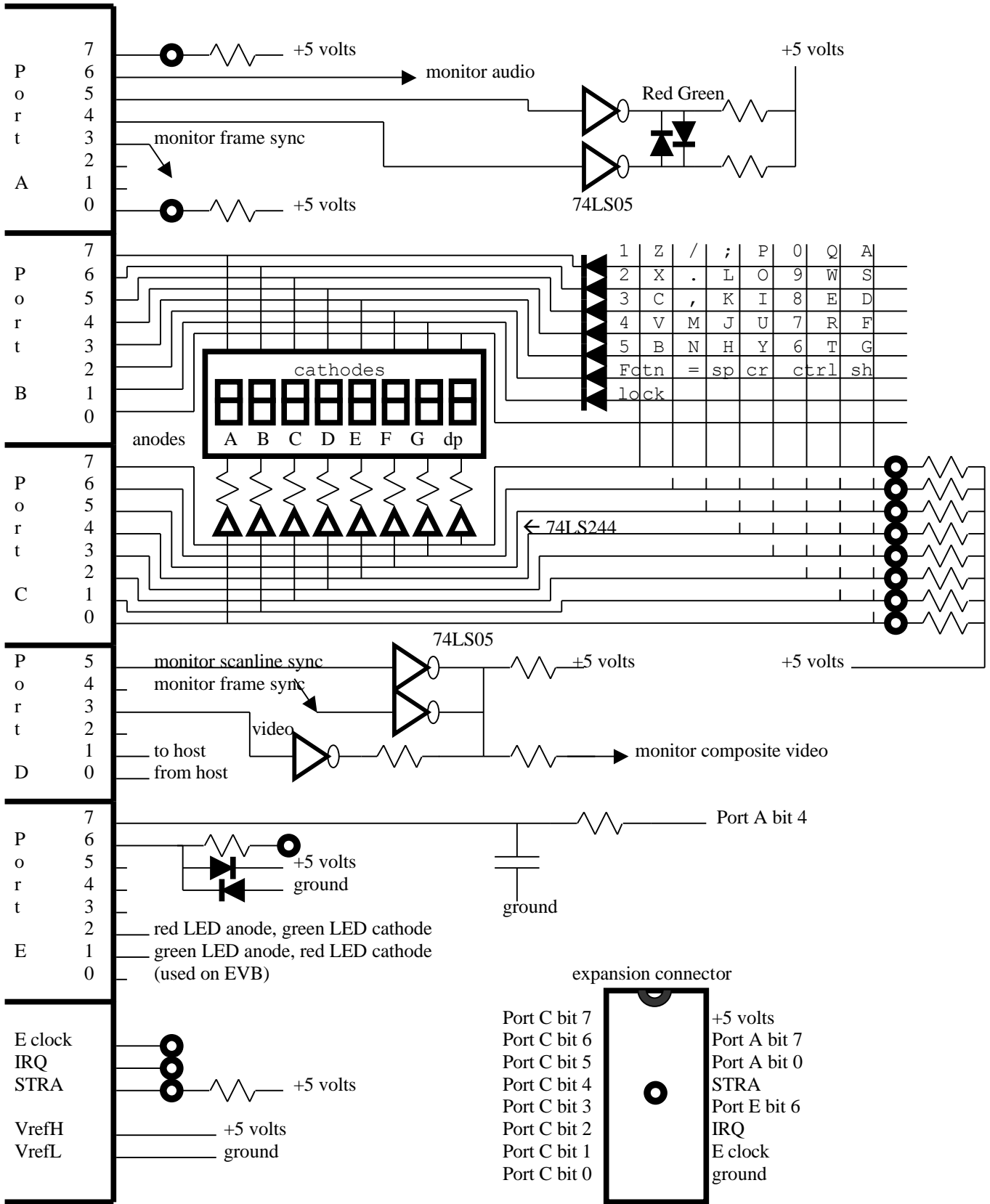
Port A

Port A in the MC68HC11 is the port used for detailed timing input and output, and it includes the Pulse Accumulator feature which allows responding to external events or counting external transitions. The Pulse Accumulator is not specifically used in this station, but its input on bit 7 of Port A is made available for experimentation on the expansion connector. Bit 7 also can be either a standard input or output bit, and can be controlled by Output Compare 1 in the timing system, so this makes a good, flexible bit for external use in unanticipated external circuits. Bit 6 drives the audio output, which can be used to make sounds either under software control of that bit or under the control of the Output Compare 2 unit in the timing system. Bits 5 and 4 are used to control the two-color LED. If bits 5 and 4 are 01, the LED shows green. If they are 10, the LED shows red. Bit 3 of Port A is the frame ("vertical") sync signal for the CRT display, and normally generates a 60 Hz signal under the control of Output Compare 5 in the timing system. This is described in more detail in the "CRT Display" section below. Bits 2 and 1 of Port A are not connected, but bit 0 is brought out to the expansion connector so that user circuits can make use of the Input Capture feature of the MC68HC11's timing system.

Port B

Port B is the simplest of the five ports in the MC68HC11, serving only as a general purpose 8-bit output port in the configuration used in the lab. In this lab station, Port B drives the rows of a multiplexed matrix alphanumeric keyboard, and also drives the cathodes of an 8-digit 7-segment common cathode multiplexed LED display. To use the keyboard, a single 0 is moved down the bits of Port B, from one keyboard row to the next, and as each row is thus "scanned," the keyboard columns are checked (via Port C, below) to detect and debounce pressed keys. To use the 8-digit LED display, digits are "selected" one at a time with a single 0 on their common cathodes from the appropriate bit of Port B, while current is supplied into the anodes of the segments to be lit for that digit (through Port C, below). Each of these operations requires a fairly involved process of repetitively scanning the single 0 through the rows of the keyboard and/or across the cathodes of the digits. These tasks are worthy of lab experiments towards the end of an introductory microprocessor

Figure 1. Lab Station Circuits Added to MC68HC11 EVB

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course. However, Port B can be used for very simple 8-bit parallel output to the 8-digit display without students knowing anything complicated. By leaving Port C in the input configuration (default after reset), anything stored in Port B will show up on the digits of the display. Any digit in the position of a 0 on Port B will be lit (all segments on) and any digit in the position of a 1 on port B will be dark (all segments off). A minor drawback of this unusual use of a multiplexed display is that the digits get dimmer as more and more digits are lit simultaneously, but with the current levels supplied in the circuit as shown, the effect is not objectionable.

Port C

Port C is the most flexible port on the MC68HC11. It can serve either as general purpose input or output, on a bit-by-bit basis, as specified in a direction register for the port. Because of its flexibility, it is chosen as the one 8-bit port to be made available to external circuits through the expansion connector. Along with port C, the expansion connector also provides the "strobe A" (STRA) signal for latching data into port C from an external source. Port C is available for arbitrary external use as long as the alphanumeric keyboard and 8-digit LED display are not in use on the lab station. If either of those devices is in use, then Port C is not available for external use. Port C includes a pullup resistor on each bit, to provide default logic 1 values when nothing drives the port. This is important for the keyboard operation, and also accommodates the "simple" use of Port B as an 8-bit parallel display port, as described above. As long as no keyboard keys are pressed, and Port C is configured as an input port, external circuits will see only one LSTTL load plus a 10K pullup resistor on the Port C pins provided on the expansion connector, which generally will not load external circuits objectionably. In operation of the multiplexed matrix keyboard, Port C receives "column" information from the keyboard matrix, recording a 0 in a bit position corresponding to a pushed key in the row presently being scanned by the 0 from Port B. Switch data must be detected and debounced through software in the processor. In operation of the 8-digit 7-segment LED display, Port C supplies the data for the anodes of the digit presently selected by the 0 on Port B, as described above. Port C data is amplified by drivers to supply adequate current to provide acceptable brightness on the LED display.

Port D

Port D is the 6-bit communications port, implementing the Serial Peripheral Interface (SPI) and the Serial Communications Interface (SCI). The SCI is connected on the EVB to RS-232 drivers and receivers and then through a connector to the lab host computer. Bit 0 is the receive data signal, and bit 1 is the transmit data signal for the SCI. The SPI is used to generate the video signal for the CRT display as described below, with a bit rate of 1 Mbit per second. This video signal emerges on bit 3 of Port D (master out slave in). Bit 2 (master in slave out) and bit 4 (slave clock) are not used. Bit 5 is used as a general purpose output bit to provide the CRT scanline ("horizontal") sync signal, which is generated by software and runs at 15360 Hz, as described below.

Port E

Port E is the analog input port. Each of its 8 pins can be separately digitized to form an 8-bit number representing the voltage on that pin. Pin 7 is connected to a grounded $1\,\mu F$ capacitor which is charged and discharged through a 100K resistor connected to Port A bit 4. By digitizing the voltage on Port E bit 7, students can investigate the RC time constant involved in charging and discharging the capacitor through the 100K resistor. Bit 6 of Port E is provided on the expansion connector so that external analog signals can be applied and digitized. The resistor and two diodes on bit 6 protect the input by clamping the applied voltage to stay within the power supply limits. Finally, bits 2 and 1 are connected on either side of the two-color LED, so that students can measure the voltage across the red LED and the green LED when each of them is turned on, and observe the difference between the properties of the two LEDs. Bits 3, 4, and 5 of Port E are not connected. Bit 0 is used on the EVB by the monitor software.

Expansion Connector

The expansion connector gives access to several useful signals in the lab station so that external circuits can be conveniently connected. Signals available are:
1.   Power supply (+5 volts and ground)
2.   all 8 bits of Port C
3.   two bits of Port A (bit 7, pulse accumulator, and bit 0, input capture)
4.   STRA for latching external data into Port C
5.   Port E bit 6 for external analog input, clamped to protect the 68HC11 input
6.   Interrupt request input (IRQ)
7.   2 MHz clock signal (E clock)

Using a 16-pin ribbon cable, these signals can be connected to an external breadboard to allow additional circuits to be interfaced to the lab station.

CRT Display

The CRT display provided in this lab station uses a standard CRT monitor but with the scanlines running vertically, from bottom to top, so that the long dimension of the display is vertical rather than horizontal as is more common. This makes the limited resolution available along a scanline due to the 1 Mbit bit rate on the video signal less of a problem in generating images on the CRT.

The monitor software included in the lab station generates an alphanumeric display of 4 lines of 16 characters each on the CRT. This is a small display by any measure, but it is adequate for interacting with a host computer and provides an example of how the SPI in the MC68HC11 processor can be used to generate rapid bit streams of data, as required on the CRT video signal. The monitor software responds properly to various control characters to implement cursor addressing, tabs, insertions, and deletions, and thus, with the proper terminal description in the host system, can be used with screen editors such as vi for file creating and editing. Admittedly, a 4 line by 16 character screen is a minimal venue for use with a screen editor, but it DOES work and can be used successfully. A side benefit of the

small number of characters on the screen is that the characters themselves are large, accommodating students who may have visual disabilities.

The monitor software produces the CRT image by using Output Compare 5 to generate interrupts every sixtieth of a second and to generate the frame sync signal. That interrupt service routine then produces the scanline sync signal under software control, and outputs video data through the SPI synchronized to the scanline generation controlled by the scanline sync. The video, scanline sync, and frame sync are combined by the 74LS05 chip to produce the composite video required by the CRT monitor. The timing of signals generated in this service routine is critical, and must be correct at the clock-cycle level, which involves counting instruction execution times and equalizing path lengths through the code in the service routine. However, that is all done, and does not need to be modified in student lab experiments. The option is there, however, for exceptional students to produce 8 x 200 bitmapped displays or possibly larger displays for graphical presentation through CRT images, which could form the heart of very challenging lab exercises.

Monitor Software

The monitor software provided with this lab station allows users to interact with the lab station hardware by modifying memory locations and running programs at specified locations in memory, and also allows interaction through the lab station with the host computer for editing and assembling assembly language files and then downloading the resulting object files into the lab station's memory for execution. The software supports five user commands, specified by typing the first letter of each command name.

1. <u>Memory</u> – prompts for an address in memory, shows the contents of that address, and allows the user to enter new data for that address.
2. <u>Register</u> – prompts for a register name (A, B, X, Y, CC, SP, or PC), shows the contents of that register, and allows the user to enter new data for that register
3. <u>Online</u> – makes the lab station transparent, so that anything typed on the lab station keyboard is sent to the host computer through the SCI, and anything received via the SCI is put on the CRT display of the lab station.
4. <u>Load</u> – exactly like Online except that the station continually watches for the capital S character from the host, and when it sees that character, it assumes that an object file in "srecord" format is coming, which it captures and stores into memory.
5. <u>Go</u> – prompts for an address, and then jumps to that address to execute the program that starts there.

The monitor is intentionally simple, and does not have a bewildering array of options to remember. It occupies less than 8K bytes of EPROM.

The evaluation board is configured to reset in "Special Test Mode" rather than The "Expanded Multiplexed Mode" which is normally used with the EVB. In "Special Test Mode" the reset and interrupt vectors are stored at the end of the 8K block of memory from A000-BFFF$_{16}$, rather than at the end of E000-FFFF$_{16}$. The EPROM containing the new monitor is inserted in the vacant socket on the EVB, so that Motorola's BUFFALO ROM can remain on the board in case it is needed in the future. Thus, nothing is modified on the Evaluation Board itself, except for a couple of jumpers which change the reset mode and

move the location of the extra memory socket from $6000\text{-}7FFF_{16}$ to $A000\text{-}BFFF_{16}$. Special Test Mode offers the additional advantage of disabling the "time protection" feature that prevents users from modifying several characteristics of the processor once 64 clock cycles have expired after reset. In Special Test Mode, such restrictions are not imposed, and students have full control over the processor configuration.

Lab Experiments

The laboratory experiments play a very important role in our microprocessor course. Laboratory exercises begin with familiarization with the system through execution of the monitor's basic set of commands and the microcontroller's set of instructions, later continuing with the use of the microcontroller's hardware resources such as the input/output ports, a/d converter, programmable timer, serial interface, etc.

Below is listed the laboratory exercise sequence, with a brief statement of the major objectives of each experiment.

Laboratory I
To introduce students to the use of the microcontroller system, and become familiar with the monitor software

Students experiment with monitor commands, examining and modifying registers and memory locations. They download and run short programs, and verify the execution of instructions and the modification of registers and memory location contents, as well as the change of values for the system's flags according to the result of an operation or state of the microcontroller.

Laboratory II
To introduce students to the 68HC11 assembly language

Students will experiment with the set of data modification and movement instructions, arithmetic and logic instructions, conditional and unconditional branching, and addressing modes. In particular they will write a program to transfer and verify data between blocks of memory using pointers.

Laboratory III
To use subroutines and parameter passing techniques

In this lab students learn and experiment with using registers, memory locations and the stack to pass parameters to a subroutine. In particular they have to implement subroutines to perform an integer division using sequential subtractions, to perform a multiplication using sequential additions, and to calculate the factorial of a number using a recursive subroutine. They compare results with instructions IDIV, FDIV, and MULT.

Laboratory IV
To learn about instruction and subroutine timing, and implementation of time delay routines

Students implement timed subroutines to generate musical notes and to simulate a piano keyboard using some keys on the alphanumeric keyboard.

Laboratory V
To introduce students to the enabling, handling and servicing of an interrupt request using the IRQ interrupt

Using the multi-digit LED display available in the system, students will write a main program to show a specific character pattern, (e.g. the sequence 1, 2, … 8, 1,.. in a continuous way). Then the interrupt service routine should use the same displays to show a different character sequence (a, b, c, …). The interrupt service subroutine should be written such that nested interrupts are enabled.

Laboratory VI
To learn about the use and programming of the analog-to-digital converter

Students will implement a temperature controller, using a thermistor as the sensor. In this experiment students learn about analog signal conditioning, and sensor characterization and linearization techniques

Laboratory VII
To familiarize students with the use of the programmable timer and counters

Students measure the exponential decay of the voltage on a capacitor as it discharges through a resistor. In this experiment students learn to program the timer, and to use the output compare registers. Students write subroutines to plot the graph of the capacitor's voltage discharge, by taking timed samples of the capacitor's voltage

Laboratory VIII
Small Controller Implementation using the timer and parallel ports

Students will implement a main program and a set of subroutines to control a radio controlled car. A commercial radio controlled car is modified to be driven by the 68HC11.

Experience in the Lab.

Our experience with the students using this system is that they like the simplicity of the monitor commands, the completeness of the resources of the system, and the possibility of straightforward connections to external devices and signals. Also, they commented about the possibility of using the system to implement their senior projects. The only drawback we detected, if any, was the small number of characters per line that can be displayed on the CRT.

Summary

Described here is a new lab station using the familiar MC68HC11 EVB as its foundation. This lab station, unlike others, offers significant I/O features that allow the station to emulate a terminal using an integral alphanumeric keyboard and a CRT display produced via a standard composite video signal generated by the MC68HC11 lab station itself. The station uses minimal hardware in addition to the EVB, and makes nearly all of the processor's I/O features available to experimenters, either through the lab station circuits themselves or through external access through an expansion connector. This lab station has

been used successfully in our introductory microprocessor class, and will continue to form the focus for that laboratory in the foreseeable future.

References

1. Carroll, C. R., "*Early Engineering Exposure Using A Microcontroller-Based Personal Lab Station*," 1990 North Midwest Section Meeting of ASEE, Houghton, MI (1990).

Biographies

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