Portable Input/Output Instrument for Interfacing Student Digital System Designs

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ABSTRACT

Any digital system must include some capabilities for input of data and output of results if the design is to be of any use. In student digital designs, these input/output capabilities, though essential, often overshadow the core of the design in the mind of the student designer so that s/he spends more time implementing the interface than addressing the intended focus of the system. The result is a system with a glamorous interface but compromised or limited capabilities to solve the overall problem.

Described in this paper is a microcontroller-based instrument built into an old telephone handset that provides keypad input and multi-digit display output, which is easy to incorporate into typical digital designs. The keypad in the telephone handset is used as the input device, and a raster generated on a standard oscilloscope is used to produce a display showing a multiple-digit output. This device has been used as a standard interface for many different digital systems designed by students in the second quarter digital circuit design class at the University of Minnesota Duluth. Designs such as multipliers and other arithmetic circuits, stacks, queues, and other data structure implementations, and standard circuits meant to teach digital circuit capabilities have used this instrument to provide user interface to the systems, so that students can concentrate on the specific task involved with their system designs and just use the available input and output tools provided here to get data into and out of their systems. This approach has resulted in improved student ability to master digital system design without undue focus on the user interface.

Presented here is the design of this instrument, and the techniques used to incorporate it into various digital system designs. Examples of laboratory exercises that use this instrument as input and output are included.

SETTING

The instrument described in this paper is used to test and exercise digital systems designed by students in a second-quarter digital system design class. Students in this class have already completed an introductory course that concentrates on basic logic and synchronous state machine design. In this second class, students learn to assemble the fundamental building blocks of gates and flip-flops along with medium-scale devices such as counters, shift registers, memory, and other MSI devices to produce complete functional digital systems.

To support student designs, and to ease the interface to the user, the instrument described below provides standardized input/output functions for use in student projects, so that students can concentrate on the focus of the design's operation rather than external interactions.

Three basic functions are included in this instrument. First, a clock generator provides a two-phase clock signal for student projects, to support both synchronous and two-phase clocked systems. The clocking scheme is flexible enough to support various departures from pure synchronous clocking, such as multiple clocks derived from the main clock signal or fundamental-mode asynchronous circuits. Second, a twelve-key keypad is included in the instrument to provide user input to the designed systems. This keypad generates BCD signals for keys 0-9 plus two additional keycodes for keys labeled * and # for use in student projects. Finally, a multi-digit display is produced by this instrument on a standard oscilloscope screen, using a small raster generated by the instrument. This capability provides a multi-digit display of hexadecimal characters to be used as an output device for student projects.

To provide portability and ease of use, the instrument is built into an old telephone handset, and connects to student projects through a sixteen-wire ribbon cable and DIP plug. The keypad in the telephone handset is used as an input device, and a single coaxial cable connects to an oscilloscope for output. Power is supplied through the ribbon cable from the student project.

INSTRUMENT DESIGN

The core of this instrument is a microcontroller, the Motorola MC68HC705J1A, which is a small twenty-pin device that fits easily onto a wire-wrapped board mounted in the earpiece of the telephone handset. The MC68HC705J1A is a low-end member of the 68_05 family of microcontrollers, which is well-established and well-supported. It includes two parallel ports that provide the interconnection to the user's circuit and to the keypad in the telephone handset. The timer facility in the microcontroller is used to produce regular interrupts, from which the user's clock signals generated in the instrument are derived.

A few of the features of this particular microcontroller ease the design of the instrument. Some of the pins of one parallel port on the device have enhanced drive capability, making them ideal for use as clock signals that typically connect to many devices in the user's circuit. Also, one of the parallel ports has programmable pull-down resistors available on chip, which eliminate the need for external resistors on the column side of the matrix keypad.

No other special features are required of the microcontroller that runs this instrument. Any general-purpose microcontroller that is consistent with the small enclosure of the telephone handset could be used. The MC68HC705J1A was chosen simply because it was available, low in cost, and small in size. Many other choices could have been made, and would perform just as well.

CLOCK GENERATION

One of the three primary duties of the microcontroller in servicing student designs is providing clock signals to the user. This instrument generates two clock signals, a main clock driven by one of the high-current parallel port pins, and a second phase clock, derived from the main clock through external circuits. This instrument is intended primarily for use with synchronous designs, in which the main clock would serve as the user's "system" clock signal. However, other clocking schemes are possible.

The clock signals are produced by the microcontroller through an interrupt service routine invoked regularly by the microcontroller's timer system. The clock frequency is fixed at a few kilohertz. The rate is intentionally slow enough to avoid electrical problems inherent with the breadboard-based student designs that often include long wires and low-performance components. The rate must be high enough, however, to provide adequate response time for student projects that, for example, might have to traverse multiple states in response to key pushes on the keypad.

The second phase clock is derived from the main clock. It is assumed that the rising edge of the main clock would be the clock "tick" that causes state changes in synchronous designs. The second phase clock is produced as a short high-going pulse on the falling edge of the main clock. This second phase clock can then be NANDed with active high control signals in the user's system to produce low-going pulses for use in applications such as flip-flop preset and clear signals, or memory write-enable signals.

KEYPAD OPERATION

The keypad capability in this instrument uses the keypad built into the telephone handset as the input device. These telephone keypads are configured as a three-by-four matrix, or can be wired to simulate such a matrix, so software in the microcontroller must scan through the matrix keypad, detect newly-pressed keys, debounce the key presses, and report the key values to the user.

The four rows and three columns of the telephone keypad are connected to seven parallel port pins on the microcontroller in this instrument. A standard n-key-rollover algorithm is executed in the microcontroller software to respond to key pushes on the keypad.

The keypad interface seen by the student user consists of four signals that convey the value of the pressed key, and a fifth signal that indicates when a keypress occurs. In keeping with the synchronous nature of the interface to the user system, these signals all change on the rising edge of the main clock supplied to the user's system, making incorporation of this device into a synchronous design straightforward.

MULTI-DIGIT DISPLAY

As an output device for student designs, this instrument generates a multi-digit numeric display on a standard oscilloscope. The display shows hexadecimal digits 0-9 and A-F in a single line of characters on the oscilloscope screen.

The display is produced by generating a sawtooth waveform on the screen of the oscilloscope. The rising edges of the sawtooth provide vertical "scanlines" on the screen, which, taken as a group, produce a raster across the face of the oscilloscope. Unlike a standard television raster where the scanlines run horizontally, in this raster the scanlines run vertically and the horizontal deflection across the screen is comparable to the vertical sweep of scanlines across a television. To produce character images on this raster, a digital "video" signal is ORed with the sawtooth through a diode OR gate, so that the electron beam is deflected vertically to the top of the screen during "blank" pixels and allowed to follow the sawtooth waveform for "lit" pixels. Using this technique and character-generator data programmed into tables in the microcontroller software, images of hexadecimal characters are produced.

The student user interacts with this display as if it were a standard multiplexed digit display. Data bits identifying the hexadecimal character to be displayed are provided by the user's circuit on four pins of the microcontroller's parallel ports. A fifth signal identifies clock cycles when data are valid and meant to be displayed, while a sixth signal "homes" the display back to the character at the left of the screen. Again, these signals are entirely synchronous, for easy interaction with synchronous designs.

Requiring an oscilloscope as a display device may seem clumsy to some, and, indeed, using a calculator-style multiplexed LED display would certainly be an alternative to the current design. However, the oscilloscope display has at least three advantages. First, it requires only two pins on the microcontroller, one to control the sawtooth waveform and one to provide the "video" signal to the diode OR gate. By comparison, a 4-digit multiplexed LED display would require at least eleven pins, which would necessitate using a larger micro- controller. Second, it makes the design dependent on having an oscilloscope to be useful. This tends to keep the instrument from walking away to unapproved sites for student project development. Lastly, the generation of a character display on a standard oscilloscope provides an interesting application of microcontrollers, which might spark some interest in students for other courses.

TYPICAL STUDENT DESIGNS

Digital systems designed by students in the course in which this instrument is used range over a variety of applications. From simple synchronous counters to complicated data base systems, all designs use the capabilities of the instrument described here as the input/output interface.

Students begin the course with a review of simple synchronous state machine design, and generally build a counter with a specified count sequence as the first lab exercise. The multi-digit display is used to show the count sequence traversed by the student designs. This not only gives feedback on the correct operation of the circuit (or insight into its malfunction) but also provides an introduction to the display capability of the test instrument for use in future lab experiments.

Next come arithmetic circuits. Students design functions such as BCD adders and binary multipliers, with operands entered from the keypad and results displayed on the multi-digit display. This is where the availability of the standard input/output devices allows students to concentrate on the core of the circuits they are designing without worrying about how to get data in or out of their circuits.

Students design hardware data structures such as stacks and queues, using long shift register storage and using standard memory parts. Again, the capabilities of the instrument described in this paper are used to provide input data and to display resulting output.

Finally, the instrument described here is available for individual project design and debugging. Having completed the course that uses these capabilities, students find them very convenient in developing larger systems on their own. This instrument takes the chore out of user interaction, and lets students focus on the specific problem they are trying to solve.

CONCLUSION

In conclusion, the instrument described in this paper has been used successfully to provide input/output interfacing for student digital system designs in a second-quarter course in digital circuits. The instrument is easy to use, and non-intimidating to students, being built into a familiar-looking telephone handset. The design of the instrument itself is accessible to students, and sometimes provides incentive for further study. Its features allow students to concentrate on the issues involved in the particular experiment they are performing without concern for getting data in or out of that system. The instrument has been a successful and valuable asset in teaching students the art of digital system design.

REFERENCES

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BIOGRAPHY

CHRISTOPHER R. CARROLL received a Bachelor of Engineering Science degree from Georgia Tech, and M.S. and Ph.D. degrees from Caltech. After serving in the Electrical Engineering department at Duke University, he is now Associate Professor and Assistant Head of Electrical and Computer Engineering at the University of Minnesota Duluth. His interests include special-purpose digital systems, VLSI, and microprocessor applications.