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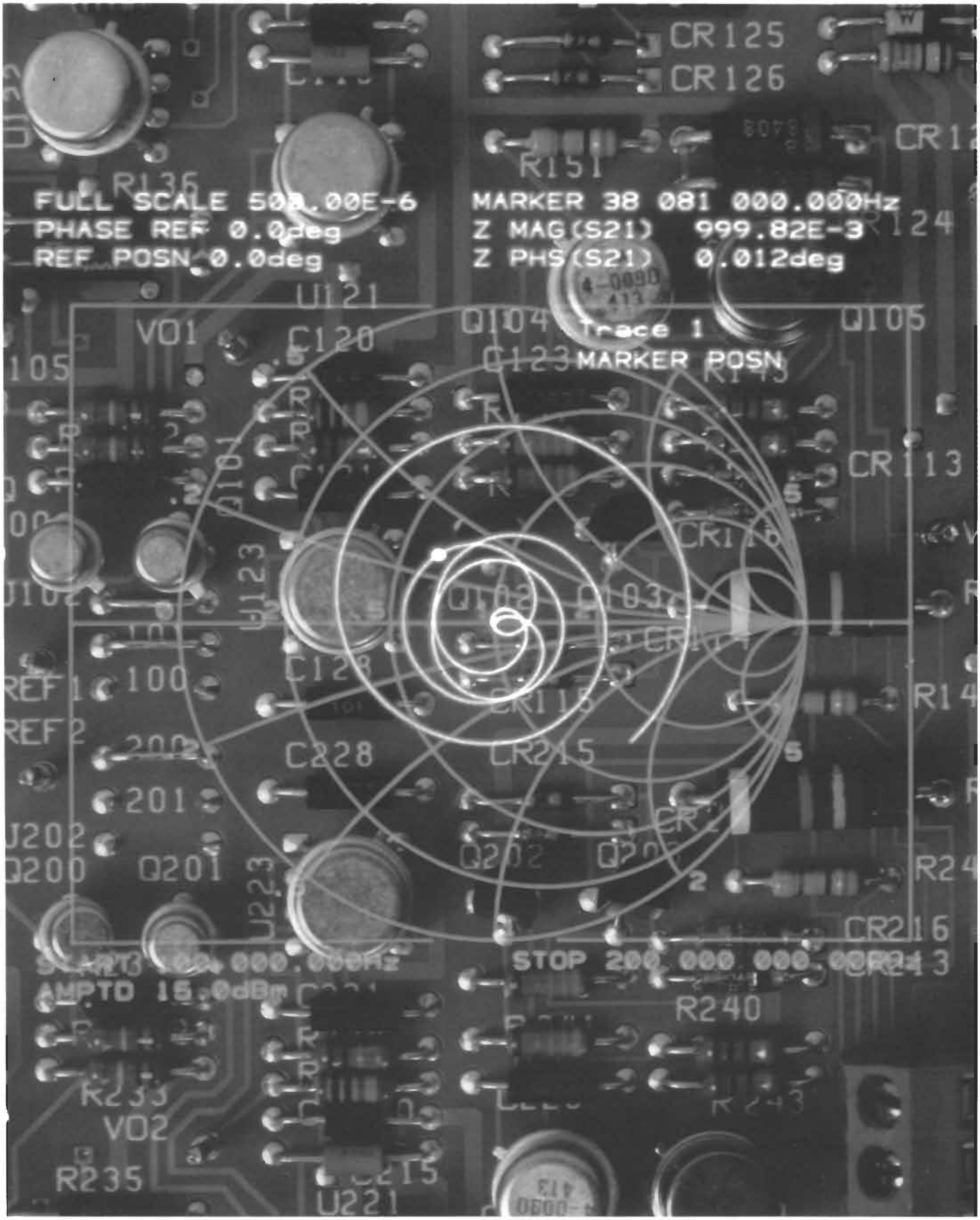


# High-Quality, Dot-Matrix Impact Printer Family

*Easy paper handling, last-form tearoff, graphics, and a friendly control panel are some of the common features.*

**by Mark J. DiVittorio**

HARD-COPY OUTPUT of results, reports, memos, order forms, charts, and program listings is frequently required for many computer applications. Equipment providing this output should be reliable, fast, and easy to use. Adding the requirement of high print quality, Hewlett-Packard developed the HP 293X Printer family to meet these needs.

The HP 2932A (Fig. 1), HP 2933A, and HP 2934A (Fig. 2) Printers are 136-column, bidirectional, dot-matrix impact printers. Common to the family is the ability to print at 200 characters per second (cps) on one-to-six-part forms up to 400 mm (15.75 inches) wide. The standard symbol font is designed to a 9×12 symbol cell matrix, with a horizontal and vertical resolution of 90 dots per inch (dpi). All three of the printers have the ability to print graphics at 21,600 dots per second. There are two standard character styles resident in all the printers—Courier (serif) and Cubic (sans serif). In addition, there are three standard pitches and ten resident languages, all of which can be selected from the printer's front panel or under host computer control.

One of the major features of this family is its simple and flexible paper handling. Various paper widths, labels, and multipart forms are accommodated. The adjustable feed tractors and the straight paper path ensure smooth movement of paper through the machine. The last-form tearoff capability (Fig. 1) saves paper, and front forms loading simplifies the task of loading and removing paper.

The interfaces offered include RS-232-C/V.24 (standard), HP-IB (IEEE 488), Centronics, RS-422, Data Link, and Synchronous Multipoint.

### Architecture

There is a basic underlying architecture to serial dot-matrix printers (Fig. 3). The data is presented at an input/output port (HP-IB, RS-232-C/V.24, ...), processed electronically, converted to mechanical drive signals, and printed as characters on a piece of paper. The HP 293X Printers contain a microprocessor, RAM, ROM, a custom IC, and the power electronics for the printhead and motors; all of

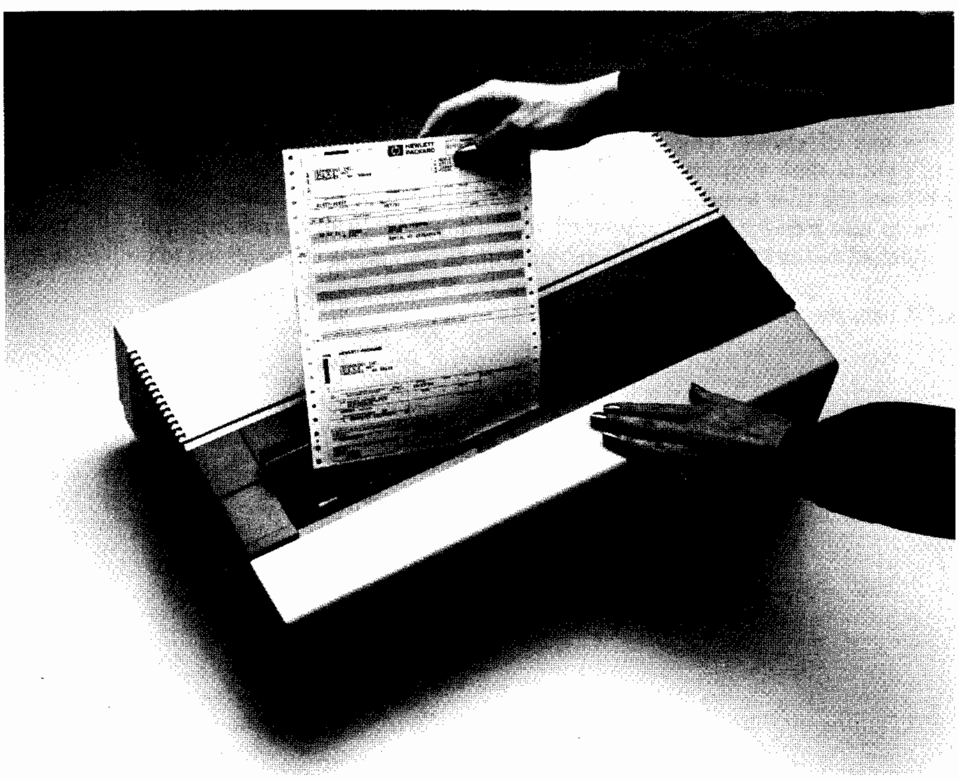


**Fig. 1.** *The HP 2932A General-Purpose Printer is the basic model of HP's 293X Printer family. All models feature last-form tearoff (shown), easy paper handling, graphics output, 200 character-per-second dot-matrix printing, and uncomplicated feature selection via a friendly front panel.*

this is required to convert the incoming data into the dots on the paper. In processing a simple character to be printed, the following must occur. The character is input, the character pattern in the character ROM is determined, and the code defining the dots that represent the character is fetched. The code for the dots is stored in a manner such that the twelve-wire printhead can be used efficiently. The custom IC handles a large portion of the details controlling the timing of when and how wires in the printhead are actuated to form the character.

Three of the major components of the HP 293X Printers are the impact printhead, the paper handling mechanism and the standard cell integrated circuit. This custom integrated circuit is discussed in the article on page 33. The printers also contain five printed circuit assemblies. The power supply electronics, the head and motor drivers, the I/O electronics, and the main logic electronics assemblies are interconnected through the fifth assembly, which functions as a main bus backplane.

### HP 2932A and HP 2933A Printers

The HP 2932A General-Purpose Printer (Fig. 1) is the basic model of the HP 293X family. The HP 2933A Factory Data Printer has two additional features that were developed for use on the factory floor. This model will automatically generate bar code patterns and print large characters up to 28 times their normal size.

### HP 2934A Printer

The HP 2934A Office Printer (Fig. 2) is the model that takes full advantage of the resolution of the mechanism and printhead that were designed for this printer family. The twelve-wire impact printhead, the paper handling mechanism, and the standard cell integrated circuit allow the HP 2934A to print near letter-quality (NLQ) text at 67 and 40 cps. The print quality is achieved by printing characters in a 36×24-dot character cell. At 67 cps the resolution is 90 dpi horizontally and 180 dpi vertically. At 40 cps the vertical resolution is identical to the horizontal resolution, 180 dpi. The 36-column-by-24-row NLQ cell is achieved with the twelve-wire printhead by printing the dots in the cell in two passes (Fig. 4). The twelve odd-numbered rows are printed, the paper is advanced a half dot width (0.0055 inch) and then the pattern for the even-numbered rows is overlaid on the first pattern.

The HP 2934A produces the near letter-quality characters by means of user-installable character cartridges. Four of these character cartridges may be resident in the machine at a time with each containing the data for a specific font at both printing speeds (67 cps and 40 cps). Fonts that are offered include Courier, Courier 12, Italic 10, Italic 12, and Letter Gothic. See Fig. 5 for some examples of the fonts printed by the HP 2934A.

### NLQ Cells

The grid that the NLQ font symbols are designed within has 36 horizontal positions and 24 vertical positions (see Fig. 4). The purpose of the dense symbol cell is to allow better symbol definition and to simulate arcs with more precision. Not all of the positions can be used in a given symbol cell because, first, the impact frequency of a wire in the printhead is limited to 1800 Hz. Second, a line of text (when printed in the NLQ fonts) is printed with the printhead carriage moving at 20 inches per second. This rate, in conjunction with the impact frequency limit, limits the positions that can be printed in the 36×24 cell. The

**Fig. 2.** *The HP 2934A Office Printer offers letter-quality printing at 67 and 40 cps and memo-quality printing at 200 cps. High-quality graphics allows a user to add illustrations and graphs to reports and other documents printed on the HP 2934A. It is shown here with the HP 29340S Single Bin Sheet Feeder, an optional accessory for convenient use of company stationery and other single sheet forms.*

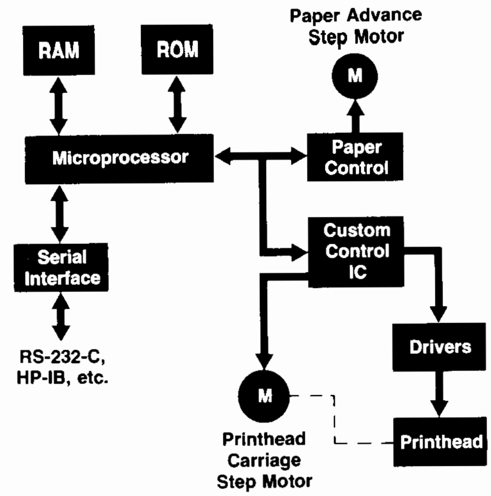



**Fig. 3.** *Basic block diagram of a serial dot-matrix printer.*

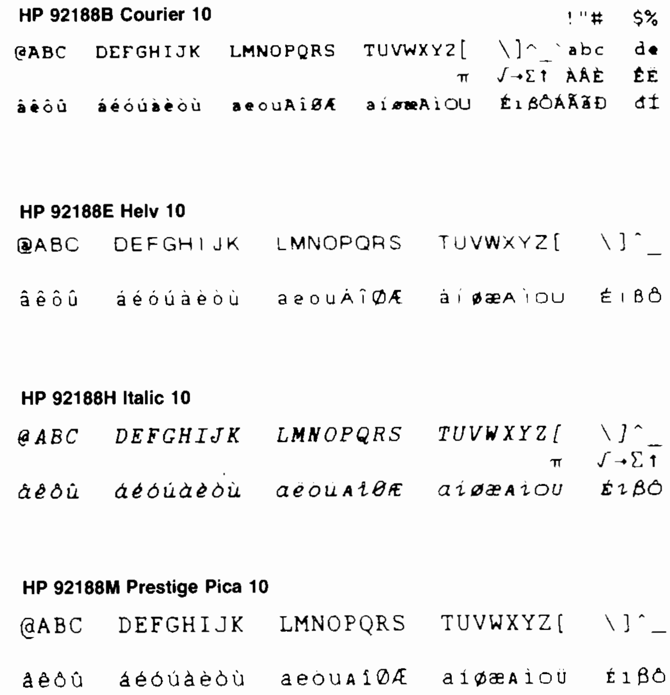



**Fig. 5.** *Examples of some near letter-quality fonts available for the HP 2934A Printer.*

resulting limitation on a given wire is that it once it has been energized it cannot be energized again for four logical dot positions. However, this does not limit the logical cell pattern for a symbol to every fourth position in the horizontal direction. If a wire in a given row is fired in column zero, the next time it can be energized is column four. But, if there is not a requirement for a dot at column four (strictly a function of the symbol to be printed), the next dot can be placed at any of the remaining positions in the cell.

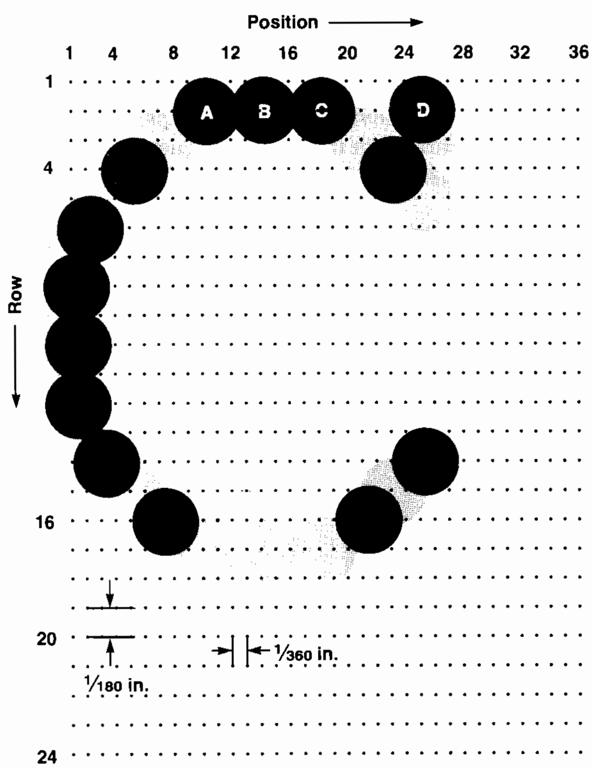



**Fig. 4.** *Near letter-quality character cells on the HP 2934A Printer are formed by two passes of the twelve-wire printhead as shown for the Courier letter C. Shaded dots are formed on the first pass, solid dots on the second pass. Because of printwire impact frequency and printhead carriage velocity limitations, dot spacing in any row of an NLQ cell cannot be any closer than one dot every four horizontal dot locations (see text).*

As an example of this symbol definition criterion, Fig. 4 illustrates an uppercase Courier C. This symbol demonstrates the limits as explained above. In the second row there are four dots that must be printed for the upper portion of the symbol. The dot labeled A at position 10 is the first dot in the row and can be printed without restriction. The next two dots (B and C) must be located four logical columns apart. This can be seen on the background grid. The next printable position on this row is position 22, but the symbol does not require a dot there. However, the symbol does require a dot at position 25, which is seven positions from the last dot (C) that was fired and is therefore a printable position.


### Acknowledgments

I would like to thank the HP 2933A and HP 2934A design team for an outstanding effort in meeting an aggressive schedule. My special thanks to Mike Ard for his diligence and perseverance and to John DiVittorio who held the mechanism to the accuracy required to print NLQ characters. My thanks to Donna Engholm, Greg Hillman, Trudy Kuehn, Dave Lee, Joe Liu, Tom Pritchard, and Mike Stein.

In addition, thanks to the HP 2932A team that provided the foundation for the HP 2934A: printhead designers Al Olson, Bill Stiggelbout, Charlie Knowles, and Kevin Kersey, print mechanism designers Jeff Grange, Alan Biggs, Olev Tammer, Chip Coffey, Chris Rasmussen, Warren Harwood, Ken Williams, and Steve Rasmussen, electronics designers David Parks, Steve Cobb, and Claude Nichols, and product designers Gene Jones, Don Bloyer, and Sohrab Vossoughi.

# Custom IC Controls Dot-Matrix Impact Printers

*This custom integrated circuit performs the complex logic required for controlling the printwires and the printhead carriage motor in a family of high-performance serial dot-matrix printers.*

**by Thomas B. Pritchard and David S. Lee**

THE ELECTRONICS used in the HP 293X Printer family includes a custom integrated circuit to interface between the microprocessor and the printhead and its carriage motor. The special characteristics of the printhead require much parallel processing with timing resolution and accuracy down to one microsecond. In addition, the open-loop stepping of the carriage motor and the open-loop firing of dots are not performed at the same time, so a method of synchronization is necessary. These features cannot be implemented in a single general-purpose microprocessor and would be uneconomical if implemented with multiple parallel processors or discrete logic. A custom IC fills these requirements while providing many other beneficial features.

To illustrate the advantages of using a custom IC, Table I shows a comparison between the TTL breadboard used during development to simulate the custom IC and the custom IC itself. Not including the additional cost of a larger power supply, more bypassing, and the larger printed circuit board area, the production cost of the TTL implementation would have been 6½ times the cost of the custom IC, even after amortizing the development cost of the IC over the expected life of the product. Several other significant advantages of a custom IC are easier and faster testing, ability to choose a package pin configuration to minimize printed circuit board layout interconnect, and lower inventory parts count.

**Table I**

Comparison of Discrete TTL Versus Custom IC

| | TTL | IC | Units |
|---|---|---|---|
| Number of ICs | 296 | 1 | |
| Total number of pins | 4364 | 40 | |
| Board space | 1050 | 8 | $cm^2$ |
| Maximum worst-case power | 13 | 0.6 | watts |

### Circuit Requirements

Fig. 1 shows the operating environment for the custom IC. The inputs to the chip from the eight-bit 8051 microprocessor controller are a six-bit-wide data bus, a four-bit address bus, and a control bus. Outputs supplied by the chip are twelve printwire control signals sent to the printwire drivers and four-phase control signals sent to the printhead carriage motor.

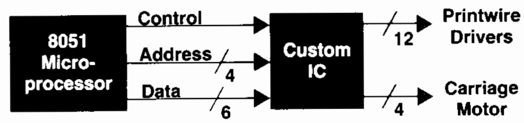
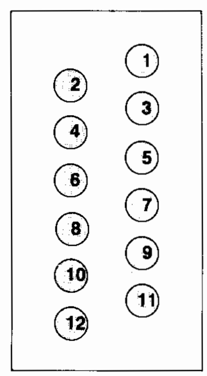



**Fig. 1.** *The custom IC used in the HP 293X Printers interfaces the controlling microprocessor in these printers with their printhead and its carriage drive motor.*

(a)




(b)

**Fig. 2.** *(a) Configuration of the printwires on the HP 293X printhead as viewed looking through the printhead to the surface of the paper. (b) Photograph of printhead.*

Fig. 2 shows the physical arrangement of the twelve dots on the printhead. The twelve printwires are arranged in two columns of six wires each. The dots made by one column are staggered vertically with respect to the dots made by the other column. One column consists of only even-numbered dots and the other column consists of only odd-numbered dots. Because of the separation of the two columns, a timing delay is required for firing the second column. For example, to print a vertical solid straight line on the paper when the printhead is moving from left to right, the odd-numbered column is fired first. Sometime later (depending on printhead speed), when the even-numbered column aligns with the previous position of the odd-numbered column when it fired, the even-numbered column is fired. Since the HP 293X Printers are bidirectional printers, the printwires are also activated when the printhead moves from right to left. In this case, the even-numbered column fires first and the delay is applied to the odd-numbered column.

Another requirement of the custom IC is data buffering. Consider when the printer starts from idle. The leading column of printwires begins to print first and at the same time the printhead advances. Because of the relatively wide horizontal separation of the two printwire columns, the leading column will have printed between two and eight times (depending on dot density and printhead speed) before the trailing column reaches the first firing position. Since the printing data is given to the chip one complete vertical line pattern (up to all 12 dots) at a time, it is necessary for the chip to be able to buffer up to eight columns of delayed data for the trailing printwire column.

Other printhead requirements are the maximum firing frequency and a dual-voltage, variable-length firing waveform. To produce high-resolution dot placement for near letter quality printing, but still not exceed the maximum firing frequency, a dot may only be fired at most every fourth possible firing time.

Fig. 3a illustrates the dual applied voltage waveform requirements. When initially turned on, the solenoid firing a printwire requires a short high-voltage pulse, called a kick pulse, to build up flux and get the wire moving toward the ribbon. Then the voltage is reduced to maintain the velocity of the wire. Before the wire hits the ribbon, at what is called the hold time, the applied voltage is turned off so the wire can bounce off the ribbon after impact. The wire cannot be fired again until it returns to its rest position.

An additional complication of the waveform generation occurs when the wire is fired at a high, but still allowable frequency. When the wire has just returned to its rest position, there is still residual energy in the system, composed of some magnetic flux remaining in the solenoid that fired the wire as well as some mechanical oscillation of the wire against its return stop. If the same firing waveform were immediately applied, the wire would strike the paper slightly early. Although the resulting dot placement error would be acceptable, this unfortunately would also result in too much energy delivered to the wire. The wire would strike the ribbon harder, leaving more ink on the page and producing inconsistent darkness of dots, which is unacceptable. In addition, this would prevent the wire from bouncing off the ribbon fast enough, and since the printhead is moving relative to the ribbon, the ribbon could tear. The chosen solution to the problem is to shorten the hold pulse width whenever the same wire was just fired a short time earlier. This can be seen in Fig. 3a by comparing the waveforms for wires one, nine, and eleven.

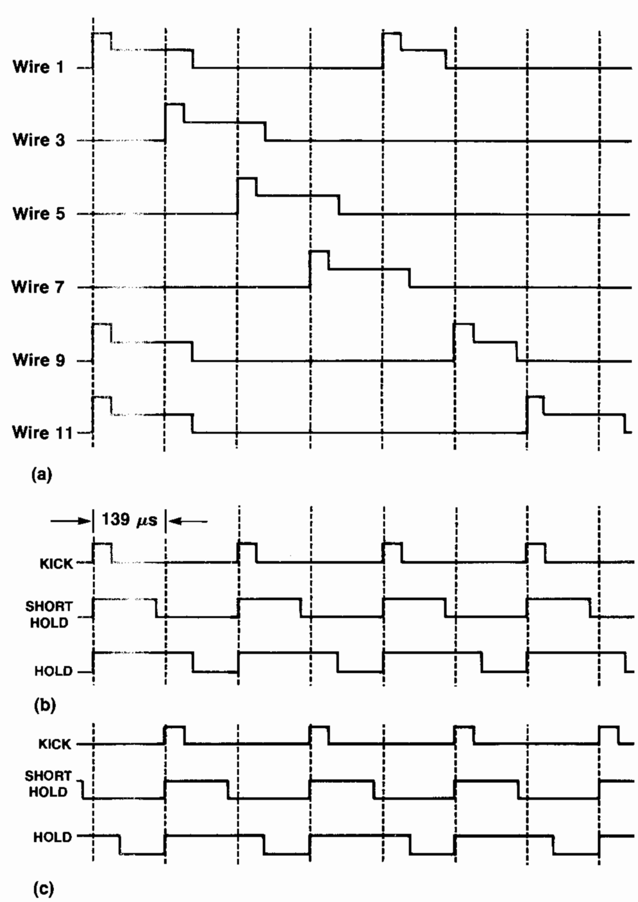



**Fig. 3.** *Typical firing and timing waveforms for the odd-numbered printwires in the right column (looking toward the paper). Note that each wire cannot be fired more than once every four intervals (139 μs per interval). (a) Firing waveforms. Note dual voltage levels and varying hold times (see text). (b) Timing waveforms for generator A (see Fig. 5). (c) Timing waveforms for generator B.*

The printhead carriage motor in the HP 293X Printers is a unipolar four-phase step motor. To control the speed and direction of the carriage, the custom IC must supply the appropriate four phases to drive the motor. One of the requirements of the chip is that it be able to handle a wide range of printhead carriage speeds in both directions and yet require minimum attention from the control microprocessor. Another requirement is ramp-up and ramp-down timing. The stepping of the carriage motor must also be synchronized with the firing of the printwires. Because the carriage motor control is an open-loop system, this synchronization between the location of the carriage and the firing of the wires is crucial to eliminate cumulative errors.

## Circuit Operation

Fig. 4 shows a block diagram of the dot input and carriage

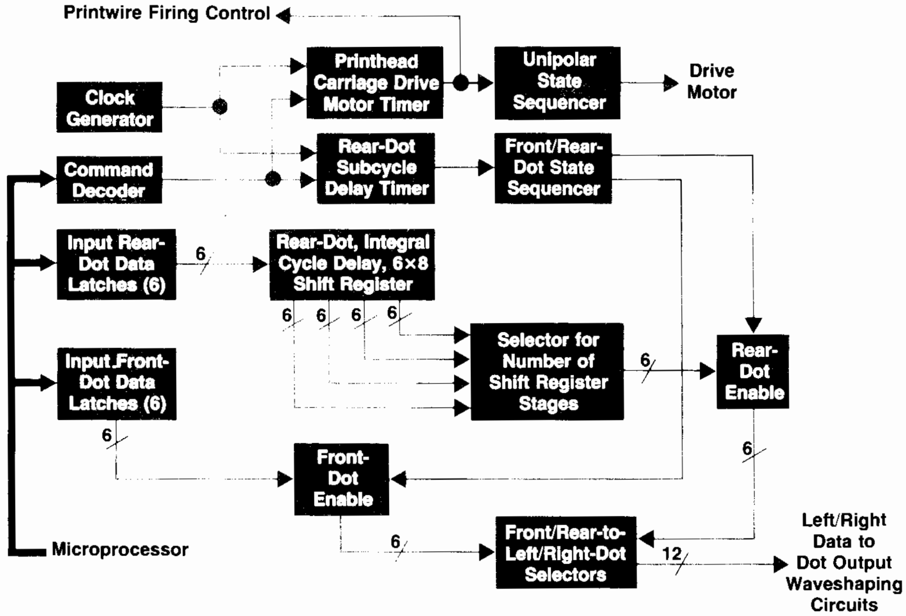



**Fig. 4.** *Block diagram of dot input and carriage motor control portion of the custom IC for the HP 293X Printers.*

motor control circuitry portion of the custom control IC used in the HP 293X Printers. As mentioned earlier, the dot data supplied by the control microprocessor must be buffered for the trailing column of printwires. Depending on the direction of the carriage motor, the data for the leading column is sent to the front-dot data latches and the data for the trailing column is sent to the rear-dot data latches and delayed by a shift register according to the horizontal dot density required. The front/rear-dot state sequencer then enables the leading and trailing column firing times according to the current carriage motor velocity.

The carriage motor control circuit consists of a four-bit state machine and an eight-bit-wide programmable timer. The output of the timer clocks the state machine, which generates the waveforms required by the carriage motor. The programmability of the timer allows a wide range of printhead velocities.

Since the printing mechanism is an open-loop system, a registration error might accumulate. This could be a significant factor affecting print quality, particularly when a long line is printed. The custom IC solves this problem by feeding the output of the carriage motor timer back to the printwire firing control circuit. Hence, the firing of the wires is synchronized with the steps of the carriage motor. In addition, to assure a consistent starting point at power on, the position of the printhead is initialized by driving it all the way to the right and then returning it to the left. If the printhead is in the middle of the line at power-on, it is still driven to the right as if it were at the start of the line. Since the carriage motor torque is limited, no damage is done by driving it against the right margin stop during this initialization.

Each signal indicating when each wire should be fired must be stretched from a one-microsecond pulse to the waveform required by the printwire driver as shown in Fig. 3a. Since the waveform generators require much silicon area, it was undesirable to have one for each of the twelve wires. Therefore, only four are used, and when a wire is fired, the custom IC selects one of these four waveform generators. The four generators are divided into two pairs, one pair for each printwire column of the printhead. This is necessary since the left column is fired asynchronously with respect to the right column. Within the right column pair of waveform generators, two circuits are needed to generate the necessary waveforms for the six wires as illustrated in Fig. 3. While normally only one of these two circuits might be expected to be needed because the 139-microsecond dot rate is already generated by the 8051 control microprocessor, two generators are required because the 8051's interrupt accuracy is not sufficient to control the waveforms to a resolution of one microsecond.

Fig. 5 illustrates the waveshaping circuitry for the odd-numbered (right) column. Identical logic circuitry is used for the even-numbered column. As a firing pulse comes in, the circuit checks to see which of the two timers is just starting its cycle and the data gets latched in the appropriate A or B hold-time flip-flop. The wire settling timers, one for each wire, indicate how long it has been since that same wire was last fired. The wire settling timers and the hold-time flip-flops combine the waveforms shown in Fig. 3b and 3c to generate the independent firing waveforms shown in Fig. 3a. The kick and hold data for each wire is multiplexed on the outputs to reduce the IC package size to 40 pins. The data is then externally demultiplexed and the actual 36.5V kick and 6.5V hold voltages are generated.

Since development of this IC was done in parallel with that for the printhead, not all of the characteristics of the head were known at the time. Because of this, it was necessary to make many functions programmable, including the kick, short-hold, and hold times. In the final implementation, the kick time is varied by the firmware, the value being a function of the power supply voltage. However, the short-hold and hold times, once programmed during initialization, are constant.

Because of the rubbing of moving paper, printhead, and ribbon, and because of frequent user interaction, electrostatic discharge (ESD) is a common problem in printers. If, because of ESD, a microprocessor is allowed to send illegiti-

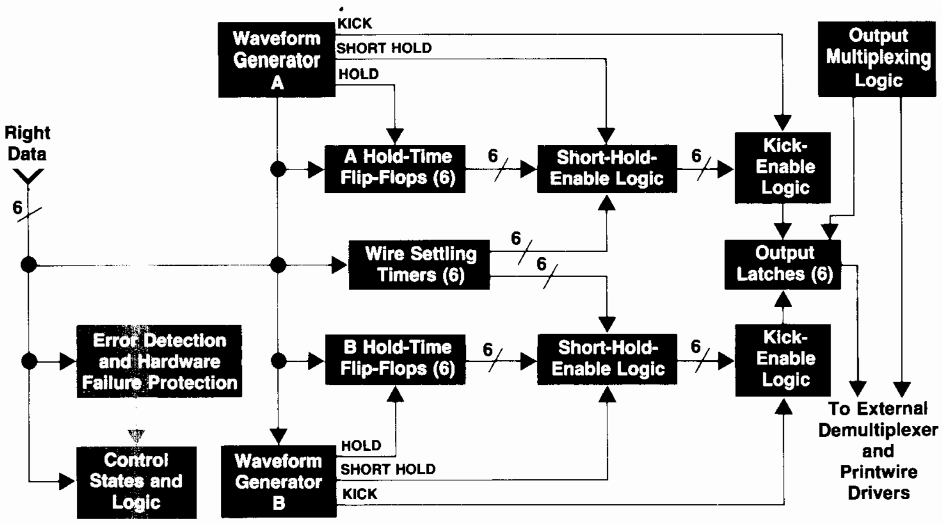



**Fig. 5.** *Block diagram of dot output waveshaping portion of the custom IC for the right (odd-numbered) column of printwires.*

mate commands, it may cause a hardware failure in the electromechanical system and may require a service call. To reduce the possibility of this happening, the custom IC will reset itself if it detects certain fault conditions.

### Implementation

The first step in the implementation of the custom chip was the development of a TTL IC simulator. This enabled the firmware engineers to start working before the IC fabrication was done, and also provided feedback for necessary design changes because of unexpected system characteristics. For example, the original breadboard did not perform the short-hold function; it was well into the project when it was decided that the IC design should be changed to incorporate this feature. The original breadboard was wire-wrapped; the later simulator used stitch-wire connections.

A proprietary NMOS process developed by HP was chosen based on economic considerations. A standard cell approach was used as the best compromise in this project between IC manufacturing cost and development time. The die, which measures 6440 μm by 6250 μm, is mounted and bonded in a plastic dual in-line 40-pin package.

The proprietary HP software development tools and design processes used to generate this custom IC included schematic capture, evaluation, logic verification, fault simulation, automatic placement and routing, timing simulations, and test pattern generation. The schematic capture, evaluation, and timing simulations were performed on HP 2647A Graphics Terminals using an HP 3000 Series 68 Computer. The logic verification, fault simulation, and test pattern generation were performed on HP 2647A Terminals using an HP 1000 E-Series Computer. The automatic placement and routing were performed on an Amdahl 470.

### Acknowledgments

Many people were involved in the development of the custom IC for the HP 293X Printer family, both at HP's Vancouver Division and Cupertino IC Operation (CICO). In Vancouver, Eric Ahlvin contributed to electronic system design and development tools. John DiVittorio, Mark DiVittorio, and Mike Sproviero helped decide on the selection of CICO as the supplier of the IC. In Cupertino, Jim Kirkpatrick, Dave Sternlicht, Troy Gau, Tom Shillingburg, and many others provided very fast responses to implement many new development tools and processes quickly.

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