

## Description

### Field of the Invention

This invention relates to the field of digital logic circuits and, more particularly, to programmable and reprogrammable logic devices, and a graphics-oriented system for programming such devices.

### Background of the Invention

In the field of digital systems design, considerable efforts have been directed towards shortening product-development cycles. One of the significant factors in the length of such product development cycles is the time required for the design and fabrication of digital integrated circuits (IC's). Once a circuit design is completed, it generally takes at least four weeks, and often several months, to fabricate a silicon version of the circuit in a "chip." To reduce the design and fabrication interval, attempts have been made to provide various types of user-definable, or programmable, logic devices (PLD's). Prior PLD's include, inter alia, programmed logic arrays (PLA's) and gate arrays.

In the field of programmable logic, there are generally four strata of integrated-circuit customization available: (1) full custom IC's; (2) standard-cell-based IC's; (3) mass-programmable IC's, such as gate arrays; and (4) user-programmable IC's, such as programmable logic devices. The first two alternatives involve customization of all mask layers required to manufacture the IC to the user's specifications and are therefore often referred to as "custom" IC design. The third alternative is sometimes called "semi-custom" IC implementation because only a few of the mask layers are customized to the users' specifications. The fourth alternative, user-programmable IC's, includes those IC's in which no customization of mask layers is required. The present invention falls into that latter category. The trade-offs between these various alternatives involve the time required to bring a new product design to market, engineering cost, expected unit volume, ease of use of design tools and familiarity with the design methodology.

Until recently, PLD's generally could be programmed only once, at the time of manufacture—they were generally not reprogrammable. Such programming has been accomplished by various methods. In PLA's, fusible-link technology has been employed, wherein such links are "blown" open to program these devices. In gate arrays, a custom metallization layer is deposited to interconnect the logic elements and provide the programming. Alternatively, a laser may be used to break connections in a metallization layer. The most significant limitation on these approaches is that the

device can be programmed only once. For example, after an internal fuse has been blown, the device cannot be reprogrammed. Further, since fuses can only be blown once, PLD's can only be tested destructively. Such testing methods never allow for full evaluation, so most users of bipolar programmable logic devices have resorted to extensive post-programming testing specific to their applications. Additionally, a device which is only programmable one time (i.e., at the factory or in the field) must be discarded if a programming error is discovered or a change of program is desired.

Recently, a new genre of user-programmable IC's has been developed; these new IC's are electrically-programmable and reprogrammable logic devices, such as reprogrammable gate arrays and the device and system of WO 89/03138, which corresponds to my international patent application no. PCT/US87/02392, filed September 23, 1987 and titled "Programmable, Asynchronous Logic Cell and Array." To emphasize the reprogrammability of such components, they are sometimes called "erasable, programmable logic devices," or EPLD's. By contrast with earlier program-once technologies, an EPLD can be programmed more than once; therefore, an error in programming can be corrected by simply reprogramming the device. Further, since the devices are reprogrammable, the entire device can be fully, nondestructively tested at the factory; such testing is independent of any device application and therefore need not be the user's responsibility.

In general, an EPLD comprises an array of logic elements and programmable means for interconnecting those elements. The choice of logic elements made available in the device, the interconnection mechanism and the logical and physical layout of components greatly influence the properties and capabilities of an EPLD. Consequently, EPLD's designed for one type of application may not be optimal for another type of application.

The most common earlier approaches in programmable logic devices, and a currently leading approach in EPLD's, employ variations of the PLA architecture, which is composed of an AND-array connected to an OR-array. Most PLD's add to these arrays input and output blocks containing registers, latches and feedback paths. The connections between the AND and OR arrays are programmable, as are the input and output blocks and feedback paths. Programmability of these connections is achieved through the use of fusible links, EPROM cells, EEPROM cells or static RAM cells.

Typical EPLD's are represented by the EPLD models 5C031, 5C032, 5C060, 5C090, 5C121 5C180 and related devices of Intel Corporation, Santa Clara, California, described in the Intel publication titled User Defined Logic Handbook, EPLD

Volume, 1986. Another good example of a programmable logic device is the Logic Cell Array (a trademark) from Xilinx, Inc. Both companies market EPLD's and associated development systems which provide tools to aid in the design of logic systems employing their respective programmable devices.

The Intel devices employ an architecture based on the "sum of products" PLA structure with a programmable AND-array feeding into a fixed OR-array. Design entry is accomplished by one of four methods: (1) schematic input of the logic circuit; (2) net list entry, by which the user enters the design by describing symbols and interconnections in words, following a standardized format; (3) state equation/diagram entry; and (4) Boolean equations. Intel's development system converts all design entry data into Boolean equations which are then converted to a sum-of-products format after logic reduction. The configurable logic block used in the Xilinx product is programmed either by the entry of Boolean equations or by the entry of a Karnaugh map.

The preamble portion of the independent Claim 1 is based on the article of F.B. Manning, "An Approach to Highly Integrated, Computer-Maintained Cellular...", IEEE Transactions on Computers, vol. C-26, No. 6, June 1977 (New York, US).

Other examples of programmable logic devices can be found in the literature. For example, see S. Kukreja et al, "Combinational and Sequential Cellular Structures," IEEE Transactions on Computers, vol. C-22, No. 9, September 1973 (New York, US); and P. King, "Subcircuits on Linear Arrays - A New Array Topology," Proc. of the IEEE 1985 Custom Integrated Circuits Conf., Portland, Oregon, 20 - 23 May, 1985, IEEE, (New York, US). Other references which an interested reader may wish to consult include: H.Krug et al, "Abänderbare Gatter-Anordnungen," Elektronik, vol. 35, no. 22, October 1986 (Munich, DE), at pages 170 - 176, in particular; O. Koratsu et al, "An Integrated Design Automation system for VLSI Circuits," IEEE Design and Test of Computers, vol. 2, no. 5, October, 1985, IEEE (New York, US); and R.F. Hartmann, "CMOS Erasable Programmable Logic Devices: TTL Replacement Made Easy," Electro and Mini/Micro Northeast, Conf. Record, 23 - 25 April 1985, Section 11/1 (New York, US).

While these EPLD architectures may represent an advance over prior logic systems which did not provide user programmability, they are far from ideal. The requirement that Karnaugh maps and Boolean equations be used to program these devices means the user must have extensive training in digital logic design. This, of course, limits the user base. Neither does either approach provide a tool for the modular, hierarchical design of complex

circuits. Other deficiencies will be apparent to those skilled in the art.

Accordingly, it is an object of the present invention to provide a reprogrammable digital logic device which can be programmed easily to implement a large class of digital circuits.

Another object is to provide such a device which is electrically reprogrammable.

It is a further object of the invention to provide a programmable, universal digital logic cell or set of cells which can be employed to implement a large class of digital circuits.

Yet another object of the invention is to provide a computational apparatus and architecture in which concurrency can be achieved at a very low level of granularity.

Another object of the invention is to provide a reprogrammable digital logic device which can be programmed and reprogrammed easily to implement self-timed logic systems.

Still another object of the invention is to provide a method, based upon graphics operations, to facilitate the programming of individual EPLD's as well as systems built up from a plurality of similar EPLD's.

A still further object of the invention is to provide a programmable logic device and a graphical programming environment therefor, which together support the modular, hierarchical construction of logic circuitry by means of block diagrams.

Yet another object of the invention is to provide a programmable logic device and a development system therefor, which support the translation, rotation and reflection of logic circuits and circuit blocks as part of the process of designing a system with one or more of such devices.

#### Summary of the Invention

These objects are achieved in the present invention by the use of particular programmable logic cells, and arrays of those cells, having certain characteristics. These characteristics include, inter alia, the following: (1) the ability to program each cell to act either as a logic element or as one or more logical "wire" elements (i.e., identity functions between one or more specified inputs and one or more specified outputs of the cell -- these identity functions include crossovers, bends, fan-outs, and routings running both horizontally and vertically); (2) the ability to rotate circuits (through 90° increments) and to reflect circuits about horizontal and vertical axes; (3) an integrated logic and communication structure which emphasizes local communications; (4) a simple structure at the cell level, thereby making available a very fine-grained logic structure; and (5) suitability for implementation of both synchronous and asynchronous logic, includ-

ing speed-independent circuits.

In one of its aspects the present invention provides a digital device containing an array of programmable logic cells, said array comprising:

- a. a plurality of functionally identical, programmable logic cells, each having a plurality of signal inputs and a plurality of signal outputs and being programmable to assume one of a plurality of available states;
- b. said plurality of cells being arranged operatively in a topology forming an array of rows and columns of cells such that each cell except those cells on the periphery of the array has four immediate neighbor cells; and
- c. each of said cells being disposed in one of a plurality of distinct possible cell orientations, the orientations being related such that any cell orientation can be obtained from any other cell orientation through one of a reflection, a rotation, and a rotation followed by a reflection, said array containing at least one cell in each of said orientations, characterized in that each of said cells is in a different orientation from its immediate neighbor cells.

In an exemplary implementation, each cell has two inputs and two outputs, allowing the cells to be arranged in a grid such that each cell communicates with its north, east, south and west neighbors. The cells are programmable to assume any one of several states, to provide the foregoing characteristics.

Such arrays of cells are well-suited to implementation in an integrated circuit "chip" using modern, very-large-scale integration (VLSI). On a chip, the logical wiring capabilities of the cells make it possible to "wire around" defective cells and elements. Thus, the invention shows promise for so-called "wafer-scale" integration or fabrication. If a large wafer contains a few defective cells, those cells can simply be avoided and bypassed, with the remainder of the wafer remaining useful. This may permit the fabrication of much larger chips than has heretofore been possible, since defects normally render a chip useless.

These chips can themselves be assembled into arrays and other configurations. Such an arrangement of cells (whether disposed on one or more chips) may be referred to as a "medium." For contrast and clarity of expression, an array of chips will be referred to hereinafter as a "matrix," to distinguish from an array of cells. A matrix of chips can be extended freely in any dimension desired. Thus, computing power can be increased by simply adding more chips to the matrix.

The basic logic cell is programmable and reprogrammable in accordance with existing technology adaptable to that purpose. Programming is accomplished by setting the states of an appro-

priate number of storage (i.e., memory) elements associated with each cell. In a first exemplary embodiment, the cells may be composed of NOR gates, transistor switches and gain elements for driving adjacent cells. The gain elements may be inverters or tri-state devices; the latter may also provide the switching functions.

A reduction in cell complexity and increase in cell speed may be achieved by composing the medium from two types of cells which alternate with each other. The two types of cells may differ from each other only in that inverters are added on the inputs of the cells of a first type and on the outputs of the cells of the second (i.e., other) type. The inverters, though not providing logical function, cannot be eliminated, since they provide needed gain for logical wires. Since these inverters occur in pairs, their addition does not alter the logical operation of the array; indeed, as far as the user is concerned, the inverters may be ignored and the array may be dealt with as if it contained only one kind of cell.

The invention provides a general-purpose architecture for computation and digital systems. Using a programming system such as the exemplary graphical programming environment described below, the individual logic cells may be programmed and connected together to implement an extensive class of logic circuits. Further, different cells on the same chip may operate concurrently and even independently of each other. Configurations for (i.e., programs for setting cell storage elements to create) circuit blocks such as adders, multiplexers, buffer stacks, and so forth, may be stored in a library for use in building more complex blocks. With an adequate library, custom hardware can be designed by simply mapping stored blocks onto selected portions of chips (i.e., the medium) and connecting the blocks together. This generates a tremendous savings in the time required for the development of many types of application-specific integrated circuits (ASIC's). Moreover, this approach allows the designer to construct systems at a pictorial block-diagram level, as well as at the circuit or detailed logic level. Further, blocks retrieved from the library may be moved, rotated, or reflected about a horizontal or vertical axis, to place their input and output connections on different sides and positions without altering the internal electrical operation of the block. This capability allows the user to (1) construct systems at a pictorial block-diagram level without having to be concerned about the internal structure of each block and (2) create large blocks from smaller blocks, the larger blocks also being storable in the library for recall and for use in creating even larger blocks. Further, it enhances the designer's freedom in laying out a chip design and reduces the size of the

block-function library needed for any particular application.

The invention is pointed out with particularity in the appended claims. The above and further objects, features and advantages of the invention may be better understood by referring to the following detailed description, which should be read in conjunction with the accompanying drawing.

#### Brief Description of the Drawing

Fig. 1 is a diagrammatic illustration of an exemplary portion of an array of cells according to the present invention;

Figs. 2A-2D are diagrammatic illustrations of a possible set of states for the cells of Fig. 1;

Fig. 3 is a schematic diagram for a circuit for implementing the four-state cell of Figs. 2A-2D;

Fig. 4 is a table listing the values of the control bits x and y which when applied to the circuit of Fig. 3 will produce the states of Figs. 2A-2D;

Fig. 5 is a diagrammatic illustration of an array of cells according to the present invention, utilizing two types of cells, referred to as "red" cells and "black" cells;

Figs. 6A-6D are schematic illustrations of four possible states for the red cells of Fig. 5;

Figs. 7A-7D are schematic illustrations of four possible states for the black cells of Fig. 5;

Fig. 8 is a schematic diagram for a circuit for implementing the red cells of Figs. 5 and 6A-6D;

Fig. 9 is a table relating the control bits x and y to the appropriate state of Figs. 6A-6D which they would select when applied to the circuit of Fig. 8;

Fig. 10 is a schematic diagram for a circuit for implementing the black cells of Figs. 5 and 7A-7D;

Fig. 11 is a table listing the correspondences between the control bits x and y and the states they would produce in Figs. 7A-7D when applied to the circuit of Fig. 10;

Fig. 12A-12H are schematic circuit diagrams representing the possible states of an eight-state cell according to the present invention;

Fig. 13 is a schematic diagram of a circuit for implementing the eight-state cell of Figs. 12A-12H;

Fig. 14 is a table listing the correspondences between the three control bits x, y and z and the states of Figs. 12A-12H which they select when applied to the circuitry of Fig. 13;

Figs. 15A-15D are diagrammatic illustrations showing the progression from a conventional logic diagram (Fig. 15A) to a block subsuming that circuit (Fig. 15B), to the incorporation of that block along with other blocks into a higher-level module (Fig. 15C) to the display of that higher-

level module as a larger block (Fig. 15D);

Fig. 16 is a diagrammatic illustration of an array of cells according to the present invention, showing a module formed by a group of cells therein;

Fig. 17 is a flow chart showing the steps for reflecting a block of cells about a vertical axis;

Fig. 18A shows a block in the array which is to be reflected about a vertical axis;

Fig. 18B shows the block of Fig. 18A after being reflected about a vertical axis in accordance with the steps of Fig. 17;

Fig. 19 shows a flow chart for the procedure for reflecting a block about a horizontal axis;

Fig. 20A shows a block of cells in the array which is to be reflected about a horizontal axis;

Fig. 20B shows the block of Fig. 20A after reflection about the horizontal axis 222;

Fig. 21 is a flow chart for the procedure for rotating a module in the array counterclockwise by 90°;

Fig. 22 is a diagrammatic illustration of a module in the array, which module is to be rotated by 90° counterclockwise;

Fig. 23 is a diagrammatic illustration of the block of Fig. 22 in a tentative new position after rotation but prior to translation for parity adjustment;

and Fig. 24 is a diagrammatic illustration showing the module of Fig. 22 in its final position after rotation and adjustment for parity.

#### Detailed Description of the Illustrative Embodiments

##### A First Embodiment

With reference now to Fig. 1, an array 10 of identical cells 20 (only a few of which are labelled) represents a segment of medium according to a first embodiment of the present invention. Each cell has two input connections and two output connections. One input connection (e.g., input connection 22 of cell 20') links the cell to its northern or southern neighbor; one output connection (e.g., 24) links the cell to the other of its northern and southern neighbors. The second input connection (e.g., 26) links the cell to its eastern or western neighbor and the second of the cell's output connections (e.g., 28) links the cell to the other of its eastern and western neighbors.

As the foregoing statement implies, a cell may be disposed in one of four possible orientations; these orientations are displaced at ninety degree increments of rotation, though in this embodiment each cell has a fixed orientation and is not rotatable. In the array, cell orientations alternate along rows and columns. The pattern is shown in Fig. 1. Looking at the second-from-left column of the ar-

ray, 21, each cell receives one input from its northern neighbor and supplies one output to its southern neighbor; successive cells in the column are reflected about a vertical axis (i.e., they are "flipped" horizontally relative to each other). Thus, each of cells 20A and 20C receives an input from its eastern neighbor and supplies an output to its western neighbor, whereas the converse applies to cells 20B and 20D. That is, cells 20B and 20D are flipped horizontally relative to cells 20A and 20C. In the next column, 23, the cells maintain the same east-west input-output orientations as their neighbors in the second column, 21, while their north-south input-output connections are reversed with respect to the second column. That is, each cell in column 23 (e.g., cells 20E, 20F and 20G) receives a first input from its southern neighbor and supplies a first output to its northern neighbor. This arrangement produces the four cell orientations represented by cells 20A, 20B, 20F and 20G.

Each of cells 20 can be programmed to assume (at any appropriate time) one of a number of different states, each providing an associated function. (Hereinafter, the term "state" is sometimes used to refer to the function, not just the state assignment.) To avoid unnecessary distraction from the explanation of the invention, the cell state memory is not illustrated, though it will be understood to be present. Figs. 2A-2D show a set of states in which a cell 30 may be placed; additional states may be provided at the designer's discretion. In the first state, illustrated in Fig. 2A, the output connections 24 and 28 of the cell are both connected to a logical zero source. The input connections 22 and 26 are not operatively connected to either output. In the second state, illustrated in Fig. 2B, a "crossover" type of connection is implemented; that is, two identity operations are provided. Input connection 22 is logically connected to output lead 24 without any logical transformation and input connection 26 is logically connected to output lead 28 without any logical transformation; there is no coupling between those two connection-pairs. Fig. 2C depicts a double right-angle bend: input connection 22 directly feeds output connection 28 without logical transformation and input connection 26 directly feeds output connection 24 without logical transformation; there is no coupling between those two connection-pairs. In a fourth state, such as the state shown in Fig. 2D, cell 30 implements a universal two-input logic element with a fan out of two; the universal logic element may be a NOR gate, such as the one illustrated at 32, or another element of choice.

A schematic circuit for implementing the four-state cell 30 of Figs. 2A-2D is shown in Fig. 3. The circuit comprises four tri-state inverters 34a-34d, two regular inverters 34e and 34f, two AND gates

35a and 35b, a tri-state NOR gate 36 and three transistor switches 37-39. The state of cell 30 is controlled (i.e., programmed) by two bits, labelled "x" and "y". Fig. 4 contains a self-explanatory table listing the state of cell 30 as a function of bits x and y. The tri-state inverters 34a-34d, the tri-state NOR gate 36, and the transistor switches 37, 38 and 39 are turned on (i.e., closed) when the applied control signal is high (i.e., a logical "1").

As previously stated, each cell or some cells may need appropriate gain elements between its input and output connections in order to ensure that logical wires function properly. Generally, pairs of inverters are used for this purpose. To reduce the number of inverters and thereby speed up the circuit, adjacent cells may employ opposite logic conventions on their inputs. That is, for a particular cell a high input may correspond to a logical "1", while for an adjacent cell a high input may correspond to a logical "0". For ease of reference these two types of cells may be referred to as "red" cells and "black" cells since they are arranged in the array similarly to the red and black squares of a checkerboard. Fig. 5 illustrates the resulting topology, with black cells 20-2 and 20-3 labelled "B" and red cells 20-1 and 20-4 labelled "R". Figs. 6A - 6D depict the four states of the "red" type of cell 40, while Figs. 7A - 7D depict the corresponding states of the "black" type of cell 50. The red cells and black cells differ from the basic cell 30 of Figs. 2A - 2D by the addition of two inverters in each cell; in the red cells 40, the inverters 41 are added in each output line of the cell, whereas in the black cells 50, the inverters 51 are added on each input line of the cell. When an inverter in the input circuit of a black cell is connected to an inverter in the output circuit of a red cell, the effects of the inverters cancel each other, leaving the circuit the equivalent of that which would be formed from the basic cell 30 of Figs. 2A - 2D. For this reason, the inverters have no effect on the logical operation of the array, and the term "logical identity" as used herein refers to the situation wherein an input line of a cell is connected directly to an output line of a cell as well as the making of such a connection through an inverter when opposite logic conventions are employed on the inputs of adjacent cells.

Schematic circuit diagrams for red and black cells 40 and 50, respectively, are contained in Figs. 8 and 10. With reference to Fig. 8, red cell 40 is formed from four tri-state inverters 62, 64, 66 and 68; a tri-state OR gate 72; a pair of AND gates 74 and 76; and three transistor switches 78, 82 and 84. The state of cell 40, like that of cell 30, is programmed by two bits, labelled "x" and "y". Fig. 9 contains a self-explanatory table listing the state of cell 40 as a function of x and y. Correspond-

ingly, Fig. 10 shows how a black cell 50 may be created from four tri-state inverters 92, 94, 96 and 98; a tri-state AND gate 102; a pair of AND gates 104 and 106; and three transistor switches 108, 112 and 114. The state of cell 50 is also programmed by two bits, again labelled "x" and "y". Fig. 11 provides a table listing the state of cell 50 as a function of bits x and y.

Since the term "cell" is used extensively herein, it is important to appreciate that that term has somewhat arbitrary boundaries, as Fig. 5 demonstrates. Thus, blocks of four cells may be aggregated to form a regular structure having a single type of "macro-cell" building block. Thus, the group of cells 20-1, 20-2, 20-3 and 20-4 may be considered the basic element of the structure, as suggested by the dashed line 25 enclosing them. The macro-cell enclosed by line 25 has both an input connection and an output connection on each of its north, south, east and west sides; and it can be programmed to any of 256 states. Clearly this approach may be extended in any dimension.

An array may also be built of cells of two distinct types, which provide different logic functions. This is to be contrasted with the use of red and black cells, which provide the same logic functions and differ only in their electrical implementations. However, even if two or more types of cells are employed, it is still possible to define a block, or macro-cell, such that the array may be described as being built from such a single type of block connected to its immediate neighbors.

#### A Second Embodiment

Cells which make available more than four states may also be employed. Figs. 12A - 12H depict one possible set of states for an eight-state cell 120, which is programmed by three bits x, y and z. Other states (both in function and number) are, of course, possible. Cell inputs are received on leads 123 and 125; outputs appear on leads 124 and 126. In Fig. 12G, the logic element 122 is a Muller C-element; this element is particularly useful in the implementation of speed-independent logic. The other states represented in Figs. 12A-12F and 12H are self-explanatory, including outputs set to zero, inputs wired directly to outputs (for crossovers, right-angle bends and fan-outs), and two-input OR and NOR gates. Other states which might be of interest include states containing flip-flops and more complex circuits; the C-element might be exchanged for a flip-flop, for example.

A schematic circuit diagram for the cell 120 appears in Fig. 13. This cell has five inverters 142A - 142E, a C-element 122, a NOR gate 146 and fourteen transistor switches labelled 148A - 148N. The switches are programmable by three bits

labelled x, y and z. Fig. 14 provides a table listing a mapping between bits x, y and z and the various cell states.

#### The Programming System

In international patent application No. PCT/US87/02392, I described the essentials of a graphical system for programming an earlier form of programmable logic cell and array which shares with the present invention the basic concept of a cellular arrangement of programmable logic units. That programming system is also useful in connection with the present invention and it has been enhanced to provide the system designer with even more powerful tools than were taught in the aforementioned patent application.

The programming system provides two design modes to the user: (1) a circuit mode for creating the lowest-level modules and (2) a block-diagram mode for creating higher-level modules. In the circuit mode, the user works directly with individual cells, determining the function of each cell (which may include, for example, a logic function or an interconnection function).

Collections of cells may then be treated as a block representing a functional module to be used in the block-diagram mode. In the block-diagram mode, the user does not deal directly with individual cells or logic elements but, rather, with blocks representing previously created modules. The size and location of each block reflects the actual size and location of the module in the array. Thus, a block diagram on the screen of the graphics programming terminal provides not only a functional definition of the composite module, but also the topological layout of the associated circuit.

In the block-diagram mode, the user is able to create and manipulate a complex circuit by recalling previously created modules, moving modules, flipping and rotating modules, duplicating modules, interconnecting modules, and deleting modules and interconnections. This ability to reorient modules (and, therefore, circuits) without changing their functionality facilitates the efficient interconnection of functional blocks. Figs. 15A-15D illustrate the progression from a logic diagram (Fig. 15A) to a block representing the logic circuit (Fig. 15B) to a module incorporating that circuit (Fig. 15C), and thence to a higher-level block representing that module (Fig. 15D). The techniques for transforming modules by translation, rotation and reflection (i.e., flipping) are developed below.

For purposes of the following discussion, it will be assumed (to simplify the presentation) that rectangular blocks are to be transformed. In general, though, a "block" or "module" is any region of the array, of arbitrary shape and size. A module and its

"origin" are considered to be "located" at the position of its upper left corner cell (or the equivalent, for non-rectangular modules), as a convenient convention; other definitions can be used just as easily, with appropriate modification of the text which follows. Within a module, a cell is located at coordinates (i,j), where the cell in the upper left corner of the module is at coordinates (1,1); "i" increases from left to right and "j" increases from top to bottom.

Each module has a "vertical parity" and a "horizontal parity"; these parities identify the orientation of the inputs and outputs of the module's cells. Parity will best be understood by reference to Fig. 16. There, a module 152 appears within dashed line 154. A module's horizontal parity is determined by the direction of the horizontally-directed output of each cell in the top row of the module; with respect to module 152, refer to output/input leads 156a-156f. Horizontal parity is said to be "even" or "1" if the horizontally-directed output from each cell in the top row of the module is supplied to its eastern, or right hand, neighbor. Conversely, a module's horizontal parity is said to be "odd" or "0" if the horizontally-directed output from each cell in the top row of the module is supplied to the cell's western, or left-hand, neighbor. Module 152 thus has odd horizontal parity. Vertical parity is treated in comparable fashion. A module's vertical parity is said to be "even" or "1" if the vertically-directed output from each cell in the leftmost column of the module is supplied (e.g., see leads 158a-158c) to the cell's southern, or lower, neighbor. Conversely, a module's vertical parity is said to be "odd" or "0" if the vertically-directed output of each cell in the leftmost column of the module is connected to its northern, or upper, neighbor. Module 152 thus has even vertical parity.

A row or column may also be said to have parity, with the same definitions being applied; thus, the row or column may be thought of as a module which is only one cell high or one cell wide.

To ensure that a transformed module has the correct parities, an appropriate horizontal or vertical translation of the module may be required when a module is translated, rotated or reflected. Note that translating a module by an odd number of cells in the horizontal direction will cause a reversal of the module's vertical parity and translating the module by an odd number of cells in the vertical direction will cause a reversal of the module's horizontal parity.

For a simple translation of a module, maintaining the correct parities in the transformed module is accomplished by restricting movement to an even number of cells in each direction. For reflection

and rotation, the situation is more complicated and detailed procedures are given below.

The steps for reflecting a block about a vertical axis are depicted in Fig. 17, which should be read in relation to Figs. 18A and 18B. The module shown in the dashed lines 170 in Fig. 18A is to be reflected about its central vertical axis 172 (which bisects the module through its central column, since the module is an odd number of columns wide). Broadly speaking, reflection is accomplished by (1) establishing the position of the new, transformed module in accordance with parity requirements and (2) mapping the original cells onto the cells of the new module. In detail, the reflection proceeds as follows: First, the location and dimension of the new module (i.e., the module resulting from the transformation) are initially defined to be the same as those of the original (i.e., untransformed) module (Step 192). Second, the new module's location is offset (i.e., shifted) by an odd number of cells vertically, to provide the appropriate horizontal parity; typically, the offset will be one cell in either direction (Step 194). The module may also have to be shifted horizontally, to achieve proper vertical parity; such a shift is only required, however, if the new module spans an even number of cells in the horizontal direction. Such parity adjustment is necessary to ensure that the new module contains the correct circuit. If module parity is improper, the circuit will not only be reflected about the axis, but also the circuit and its function will be altered. The parity adjustment routine begins with a test to determine whether the horizontal size of the module is even, Step 196, and a horizontal shift is performed in Step 198 if required. Having properly situated the new module, each cell of the old module must be mapped into the space occupied by the new module. In Step 202, a Pascal-type expression is given for a procedure which accomplishes that operation. This procedure comprises a pair of nested loops wherein the new cell state assignments are calculated and then replace the old cell state assignments. The outer loop is indexed by the variable "j", which denotes the vertical coordinate of a cell in the new, reflected module, relative to the module's origin (i.e., upper left hand corner). The horizontal size of the new module (i.e., after reflection), is represented by the variable `newModuleSize.h`. The inner loop is indexed by the variable "i", which denotes the horizontal coordinate of a cell in the new module, relative to the module's origin. The quantity `"newCell[i,j]"` represents the state, or function, of the cell at coordinates (i,j) in the new module; the quantity `"oldCell[moduleSize.h-j+1,i]"` represents the state of the cell in the original, "old" module at the indicated coordinates. The procedure of Step 202 first maps cell states of the old module into

cell states of the new module and then makes adjustments in the new states, as required, to reflect its reorientation. Some cell states retain their identities through the transformation. The adjustments of states for the new cells can be performed through a look-up table or other mechanism. Once the new cell states are known, the corresponding bits in the cell state memory, which control the programming of those cells, are set to the appropriate values.

The transformed module 170' is shown in Fig. 18B, from which it will be appreciated that a vertical translation was needed in order to achieve proper parities. Cells 176, 178 and 182 have been mapped to cells 176', 178' and 182'.

The steps for reflecting a block about a horizontal axis are depicted in Fig. 19, which should be read in conjunction with Figs. 20A and 20B. In Fig. 20A, a block originally shown at the position of dashed line 220 is to be reflected about horizontal axis 222. The reflection is performed as follows: First, the location and dimensions of the new module (i.e., the module resulting from the transformation) are initially defined to be the same as those of the original (i.e., untransformed) module (Step 242). Second, the new module's location is offset (i.e., shifted) by an odd number of cells horizontally, to provide the appropriate vertical parity; typically, the offset will be one cell in either direction (Step 244). The module may also have to be shifted vertically, to achieve proper horizontal parity; such a shift is only required, however, if the new module spans an even number of cells in the vertical direction. A test for this condition is performed in Step 246 and the vertical shift is performed in Step 248 if required. Having properly situated the new modules, each cell of the old module must be mapped into the space occupied by the new module. The procedure for doing so is performed at Step 252 and mirrors the procedure in Step 202 of Fig. 17 for the reflection about a vertical axis.

The transformed module 224 is shown in Fig. 20B, with cells 226, 228, and 232 mapped onto cells 226', 228' and 232', respectively. Note that both vertical and horizontal shifting was required to preserve vertical and horizontal parity.

A flow chart for accomplishing module rotation is shown in Fig. 21. This flow chart should be read in relation to Figs. 22-24. Fig. 22 shows a block within dashed line 260, prior to rotation. Fig. 23 shows the same block in its tentative new position 260' after rotation, prior to translation for parity adjustment. Fig. 24 shows the block at its final position 260" after rotation and translation.

The Fig. 21 procedure rotates a module by ninety degrees in the counterclockwise direction. First, the location and dimensions of the new mod-

ule are initialized (Step 270). This involves aligning the cells at the upper left hand corners of the new module and the old module and setting the horizontal and vertical sizes of the new module equal to the vertical and horizontal sizes, respectively, of the old module. Next, the old module's horizontal parity is compared with the old module's vertical parity (Step 272). If the two parities are equal, the location of the new module is offset horizontally by an odd number of cells (Step 274). Following that step, or following Step 272 if the parities were unequal, a test is performed to determine whether a vertical offset is required to correct the horizontal parity of the new module (Step 276). This latter step more specifically involves comparing the horizontal parity of the old module with the vertical parity of the rightmost column of the old module. The rightmost column of the old module becomes the topmost row of the new module, so a comparison of their parities will determine if the rotation will, without compensation, produce the wrong horizontal parity in the new module. If so, the parity is corrected by offsetting the new module by an odd number of cells in the vertical direction, Step 278. The function `[oldModuleParity.v XOR ODD(oldModuleSize.h-1)]` in Step 276 evaluates the parity of the column at `oldModuleSize.h-1`, where `oldModuleSize.h` represents the horizontal size of the old module, in numbers of cells. The `ODD` function is `TRUE` when its argument is odd and `FALSE` when its argument is even. Performing the exclusive-OR operation (i.e., shown as `XOR` in the drawing) on the vertical parity of the old module and the function `ODD(oldModuleSize.h-1)` yields the parity of the rightmost column of the old module, which controls whether a vertical offset is required in order to ensure that the new module will have the proper horizontal parity.

Once the new module is properly positioned so as to have the desired parity, each cell in the old module's array must be moved to the proper location in the new module's array. That is the function of Step 280.

In the latter step, a Pascal-type expression is given for a procedure which accomplishes that operation. This procedure comprises a pair of nested loops. The outer loop is indexed by the variable "i", which denotes the horizontal coordinate of a cell in the new, rotated module, relative to the module's origin (i.e., upper left hand corner). The horizontal size of the new module (i.e., after rotation), is represented by the variable `newModuleSize.h`. The inner loop is indexed by the variable "j", which denotes the vertical coordinate of a cell in the new module, relative to the module's origin. The quantity `"newCell[i,j]"` represents the state, or function, of the cell at coordinates (i,j) in the new module; the quantity `"oldCell-`

[oldmoduleSize.h-j+1,i]" represents the state of the cell in the original, "old" module at the indicated coordinates.

The flow charts of Figs. 17, 19 and 21 present only the overall procedures used for reorienting modules. In addition, various ministerial details must be carried out in connection with the implementation of these procedures; for clarity of explanation, these low-level details have not been expressly discussed, as they will be readily apparent to a skilled programmer.

In addition to implementing procedures for rotating modules and reflecting modules about horizontal and vertical axes, a graphics-based programming environment for the array is capable of allowing modules to be "dragged" across a display screen (i.e., relocated on the medium by translation of location) in the horizontal and vertical directions. As this operation involves only a simple translation of cell coordinates, its implementation will be straightforward and requires no further explanation.

Having thus described two exemplary embodiments of the invention, it will be apparent that other embodiments also may be created. It will further be apparent that various alterations, modifications and improvements will readily occur to those skilled in the art. For example, other circuits may be used for the cells and the cells may be assigned other combinations of states. Additionally, cells may be operatively connected to each other through intermediate elements, such as switching elements (which may also provide cross-overs, ninety-degree bends and other wiring functions), in addition to being directly connected.

### Claims

1. A digital device containing an array of programmable logic cells, said array comprising:
  - a. a plurality of functionally identical, programmable logic cells, each having a plurality of signal inputs and a plurality of signal outputs and being programmable to assume one of a plurality of available states;
  - b. said plurality of cells being arranged operatively in a topology forming an array of rows and columns of cells such that each cell except those cells on the periphery of the array has four immediate neighbor cells; and
  - c. each of said cells being disposed in one of a plurality of distinct possible cell orientations, the orientations being related such that any cell orientation can be obtained from any other cell orientation through one of a reflection, a rotation, and a rotation followed by a reflection, said array containing at least one cell in each of said orienta-

tions, characterized in that each of said cells is in a different orientation from its immediate neighbor cells.

2. The device of claim 1 wherein each cell has two inputs and two outputs and the four nearest neighbor cells of each cell except those on the periphery of the array may be referred to as the north, east, south and west neighbors and the device is further characterized in that each array contains cells in each of four orientations, a first orientation being one in which the cell's two inputs are connected to the outputs of its north and its east neighbors, a second orientation being one in which the cell's two inputs are connected to the outputs of its north and its west neighbors, a third orientation being one in which the cell's two inputs are connected to the outputs of its south and its east neighbors, and a fourth orientation being one in which the cell's two inputs are connected to the outputs of its south and its west neighbors.
3. The device of Claim 1 further characterized in that each of the available cell states possesses exactly one axis of symmetry.
4. The device of Claim 1 further characterized in that the available cell states have the property that for each available cell state, if the first and second cell inputs are interchanged and the first and second cell outputs are interchanged, then the resulting cell state is one of the available cell states.
5. The device of claim 1 further characterized in that the available states include at least one state wherein the cell provides at one of its outputs a logical constant value.
6. The device of Claim 1 further characterized in that:
  - a. the available cell states include a state wherein one of the cell's first and second inputs is connected as one or a logical identity and a logical negation to one of its first and second outputs; and
  - b. the available coil states include a state wherein the other of the cell's first and second inputs is connected as one of a logical identity and a logical negation to the other of its first and second outputs.
7. The device of claim 1 further characterized in that the plurality of cell states includes states providing Boolean functions of the signal inputs from which a universal Boolean logical

[oldmoduleSize.h-j+1,i]" represents the state of the cell in the original, "old" module at the indicated coordinates.

The flow charts of Figs. 17, 19 and 21 present only the overall procedures used for reorienting modules. In addition, various ministerial details must be carried out in connection with the implementation of these procedures; for clarity of explanation, these low-level details have not been expressly discussed, as they will be readily apparent to a skilled programmer.

In addition to implementing procedures for rotating modules and reflecting modules about horizontal and vertical axes, a graphics-based programming environment for the array is capable of allowing modules to be "dragged" across a display screen (i.e., relocated on the medium by translation of location) in the horizontal and vertical directions. As this operation involves only a simple translation of cell coordinates, its implementation will be straightforward and requires no further explanation.

Having thus described two exemplary embodiments of the invention, it will be apparent that other embodiments also may be created. It will further be apparent that various alterations, modifications and improvements will readily occur to those skilled in the art. For example, other circuits may be used for the cells and the cells may be assigned other combinations of states. Additionally, cells may be operatively connected to each other through intermediate elements, such as switching elements (which may also provide cross-overs, ninety-degree bends and other wiring functions), in addition to being directly connected.

#### Claims

1. A digital device containing an array of programmable logic cells, said array comprising:
  - a. a plurality of functionally identical, programmable logic cells, each having a plurality of signal inputs and a plurality of signal outputs and being programmable to assume one of a plurality of available states;
  - b. said plurality of cells being arranged operatively in a topology forming an array of rows and columns of cells such that each cell except those cells on the periphery of the array has four immediate neighbor cells; and
  - c. each of said cells being disposed in one of a plurality of distinct possible cell orientations, the orientations being related such that any cell orientation can be obtained from any other cell orientation through one of a reflection, a rotation, and a rotation followed by a reflection, said array containing at least one cell in each of said orienta-

tions, characterized in that each of said cells is in a different orientation from its immediate neighbor cells.

2. The device of claim 1 wherein each cell has two inputs and two outputs and the four nearest neighbor cells of each cell except those on the periphery of the array may be referred to as the north, east, south and west neighbors and the device is further characterized in that each array contains cells in each of four orientations, a first orientation being one in which the cell's two inputs are connected to the outputs of its north and its east neighbors, a second orientation being one in which the cell's two inputs are connected to the outputs of its north and its west neighbors, a third orientation being one in which the cell's two inputs are connected to the outputs of its south and its east neighbors, and a fourth orientation being one in which the cell's two inputs are connected to the outputs of its south and its west neighbors.
3. The device of Claim 1 further characterized in that each of the available cell states possesses exactly one axis of symmetry.
4. The device of Claim 1 further characterized in that the available cell states have the property that for each available cell state, if the first and second cell inputs are interchanged and the first and second cell outputs are interchanged, then the resulting cell state is one of the available cell states.
5. The device of claim 1 further characterized in that the available states include at least one state wherein the cell provides at one of its outputs a logical constant value.
6. The device of Claim 1 further characterized in that:
  - a. the available cell states include a state wherein one of the cell's first and second inputs is connected as one or a logical identity and a logical negation to one of its first and second outputs; and
  - b. the available cell states include a state wherein the other of the cell's first and second inputs is connected as one of a logical identity and a logical negation to the other of its first and second outputs.
7. The device of claim 1 further characterized in that the plurality of cell states includes states providing Boolean functions of the signal inputs from which a universal Boolean logical



function may be assembled.

8. A method for generating programming instructions to reflect about a vertical axis a circuit module embodied in a set of programmed cells within an array as specified in Claim 1, the module to be so reflected being termed the "original module" and the module after reflection being termed the "reflected module," the method being characterized by the steps of:

a. defining in the array coordinates a tentative location for the reflected module, such that the top row of cells in the reflected module is coincident with the top row of cells in the original module and such that the leftmost column in the reflected module is coincident with the leftmost column in the original module;

b. offsetting the tentative location for the reflected module by an odd number of cells in the vertical direction, to ensure correct, horizontal parity of the reflected module;

c. if the module spans an even number of cells in the horizontal direction, then offsetting the tentative location by an odd number of cells in the horizontal direction;

d. mapping each cell of the original module to a cell located in the reflected module and choosing a proper state for the latter cell so as to preserve operatively the circuit of the original module; and

e. generating appropriate programming instructions to cause a corresponding change in the memory which retains the states of the cells in the old module and the states of the cells in the reflected module.

9. A method of generating programming instructions for reflecting about a horizontal axis a circuit module embodied in a set of programmed cells within an array as specified in Claim 1, the module to be so reflected being termed the "original module" and the module after reflection being termed the "reflected module", the method being characterized by the steps of:

a. defining in the array coordinates a tentative location for the reflected module, such that the top row of cells in the reflected module is coincident with the top row of cells in the original module and such that the leftmost column in the reflected module is coincident with the leftmost column in the original module;

b. offsetting the tentative location for the reflected module by an odd number of cells in the horizontal direction, to ensure correct

vertical parity of the reflected module;

c. if the module spans an even number of cells in the vertical direction, then offsetting the tentative location by an odd number of cells in the vertical direction;

d. mapping each cell of the original module to a cell located in the reflected module and choosing a proper state for the latter cell so as to preserve operatively the circuit of the original module; and

e. generating appropriate programming instructions to cause a corresponding change in the memory which retains the states of the cells in the old module and the states of the cells in the reflected module.

10. A method for generating programming instructions for rotating by ninety degrees counter-clockwise a circuit module embodied in a set of programmed cells within an array as specified in Claim 1, the module to be so reflected being termed the "original module" and the module after rotation being termed the "rotated module", the method being characterized by the steps of:

a. initializing the location and dimensions of the rotated module so that the left-most column of the original module becomes the left-most column of the initial location of the rotated module and the top-most row of the original module becomes the top-most row of the initial location of the rotated module, the width of the original module becomes the length of the rotated module, and the length of the rotated module becomes the width of the rotated module;

b. if the horizontal parity of the original module is the same as the vertical parity of the original module, then offsetting the location of the rotated module by an odd number of cells in the horizontal direction;

c. if the horizontal parity of the original module differs from the vertical parity of the original module, then offsetting the location of the rotated module by an odd number of cells in the vertical direction;

d. mapping each cell in the original module to a cell in a corresponding location in the rotated module and choosing a proper state for the latter cell so as to preserve operatively the circuit of the original module, and

e. generating appropriate programming instructions to cause a corresponding change in the memory which retains the states of the cells in the original module and the states of the cells in the reflected module.



### Patentansprüche

1. Ein digitaler Baustein, der eine Matrix aus programmierbaren logischen Zellen beinhaltet, dadurch gekennzeichnet, daß diese Matrix
  - a. eine Vielzahl von in funktioneller Hinsicht identischer, programmierbarer logischer Zellen umfaßt, von denen jede über mehrere Signaleingänge und mehrere Signalausgänge verfügt und so programmierbar ist, daß sie einen Zustand aus einer Vielzahl von verfügbaren Zuständen annimmt;
  - b. die besagte Vielzahl von Zellen in operativer Hinsicht in einer Topologie angeordnet ist, daß eine Matrix aus Zeilen und Spalten von Zellen entsteht, in der jede Zelle - ausgenommen die am Rande der Matrix liegenden Zellen - vier unmittelbare Nachbarzellen aufweist; und
  - c. jede der besagten Zellen eine Ausrichtung aus einer Vielzahl von verschiedenen möglichen Zellausrichtungen aufweist, die so miteinander in Beziehung stehen, daß jede Zellausrichtung ausgehend von jeder anderen Zellausrichtung durch Reflexion, Rotation oder Rotation gefolgt von Reflexion erreicht werden kann, wobei besagte Matrix mindestens eine Zelle in jeder der genannten Ausrichtungen beinhaltet und dadurch gekennzeichnet ist, daß alle Zellen gegenüber ihren unmittelbar nebeneinander liegenden Zellen unterschiedlich ausgerichtet sind.
2. Der Baustein gemäß Anspruch 1, dadurch gekennzeichnet, daß jede Zelle zwei Eingänge und zwei Ausgänge aufweist und die vier nächstgelegenen Nachbarzellen einer jeden Zelle - ausgenommen die am Rande der Matrix liegenden Zellen - als deren nördlicher, östlicher, südlicher und westlicher Nachbar bezeichnet werden können, und ferner dadurch gekennzeichnet, daß jede Matrix Zellen in allen vier Ausrichtungen beinhaltet, wobei eine erste Ausrichtung diejenige ist, in der die zwei Eingänge einer Zelle an die Ausgänge ihrer nördlich und östlich gelegenen Nachbarzellen gekoppelt sind, eine zweite Ausrichtung diejenige ist, in der die zwei Eingänge der Zelle an die Ausgänge ihrer nördlich und westlich gelegenen Nachbarzellen gekoppelt sind, eine dritte Ausrichtung diejenige ist, in der die zwei Eingänge der Zelle an die Ausgänge ihrer südlich und östlich gelegenen Nachbarzellen gekoppelt sind und eine vierte Ausrichtung diejenige ist, in der die zwei Eingänge der Zelle an die Ausgänge ihrer südlich und westlich gelegenen Nachbarzellen gekoppelt sind.
3. Der Baustein gemäß Anspruch 1, desweiteren dadurch gekennzeichnet, daß jeder der verfügbaren Zellzustände über genau eine Symmetrieachse verfügt.
4. Der Baustein gemäß Anspruch 1, desweiteren dadurch gekennzeichnet, daß die verfügbaren Zellzustände die Eigenschaft besitzen, daß in jedem verfügbaren Zellzustand bei einem Vertauschen des ersten und des zweiten Zelleingangs und des ersten und des zweiten Zellausgangs der resultierende Zellzustand einem der verfügbaren Zellzustände entspricht.
5. Der Baustein gemäß Anspruch 1, desweiteren dadurch gekennzeichnet, daß die verfügbaren Zellzustände wenigstens einen Zustand umfassen, in dem die Zelle an einem ihrer Ausgänge eine logische Konstante aufweist.
6. Ein Baustein gemäß Anspruch 1, desweiteren dadurch gekennzeichnet, daß
  - a. die verfügbaren Zustände einen Zustand umfassen, in dem der erste und zweite Eingang der Zelle als Eingang mit logischer Identität und logischer Negation mit ihrem ersten oder zweiten Ausgang verknüpft wird;
  - b. die verfügbaren Zellzustände einen Zustand umfassen, in dem der andere der beiden Eingänge der Zelle als Eingang mit logischer Identität und logischer Negation mit dem anderen ihrer beiden Ausgänge verknüpft wird.
7. Der Baustein gemäß Anspruch 1, desweiteren dadurch gekennzeichnet, daß die Vielzahl der Zellzustände Zustände beinhaltet, die boolesche Funktionen der Signaleingänge liefern, aus denen eine allgemeine boolesche logische Funktion zusammengesetzt werden kann.
8. Ein Verfahren zur Erzeugung von Programmieranweisungen, um ein Schaltungsmodul, das in einem Satz programmierter Zellen innerhalb einer Matrix wie in Anspruch 1 spezifiziert verkörpert ist, um eine senkrechte Achse zu reflektieren, wobei das so zu reflektierende Modul "Originalmodul" und das Modul nach erfolgter Reflexion "reflektiertes Modul" bezeichnet wird, gekennzeichnet durch die nachgenannten Verfahrensschritte:
  - a. Definition einer vorläufigen Lage für das reflektierte Modul in dem Matrixkoordinatensystem, so daß die oberste Zellzeile in dem reflektierten Modul mit der obersten Zellzeile des Originalmoduls und die Spalte ganz links in dem reflektierten Modul mit der



Spalte ganz links in dem Originalmodul zusammenfallen;

b. Verschiebung der vorläufigen Lage für das reflektierte Modul um eine ungerade Anzahl von Zellen in senkrechter Richtung, um die korrekte horizontale Parität des reflektierten Moduls sicherzustellen;

c. für den Fall, daß das Modul eine gerade Anzahl von Zellen in waagerechter Richtung umfaßt, Verschiebung der vorläufigen Lage um eine ungerade Anzahl von Zellen in waagerechter Richtung;

d. Abbildung einer jeder Zelle des Originalmoduls auf einer in dem reflektierten Modul angeordneten Zelle und Auswahl eines richtigen Zustands für letztgenannte Zelle, um die Schaltung des Originalmoduls in operativer Hinsicht zu bewahren; und

e. Erzeugung geeigneter Programmieranweisungen, um eine entsprechende Änderung in dem Speicher zu veranlassen, in dem die Zustände der Zellen in dem alten Modul und die Zustände der Zellen in dem reflektierten Modul abgelegt sind.

9. Ein Verfahren zur Erzeugung von Programmieranweisungen, um ein Schaltungsmodul, das in einem Satz programmierter Zellen innerhalb einer Matrix wie in Anspruch 1 spezifiziert verkörpert ist, um eine waagerechte Achse zu reflektieren, wobei das so zu reflektierende Modul "Originalmodul" und das Modul nach erfolgter Reflexion "reflektiertes Modul" bezeichnet wird, gekennzeichnet durch die nachgenannten Verfahrensschritte:

a. Definition einer vorläufigen Lage für das reflektierte Modul in dem Matrixkoordinatensystem, so daß die oberste Zellzeile in dem reflektierten Modul mit der obersten Zellzeile des Originalmoduls und die Spalte ganz links in dem reflektierten Modul mit der Spalte ganz links in dem Originalmodul zusammenfallen;

b. Verschiebung der vorläufigen Lage für das reflektierte Modul um eine ungerade Anzahl von Zellen in waagerechter Richtung, um die korrekte vertikale Parität des reflektierten Moduls sicherzustellen;

c. für den Fall, daß das Modul eine gerade Anzahl von Zellen in senkrechter Richtung umfaßt, Verschiebung der vorläufigen Lage um eine ungerade Anzahl von Zellen in senkrechter Richtung;

d. Abbildung einer jeden Zelle des Originalmoduls auf einer in dem reflektierten Modul angeordneten Zelle und Auswahl eines richtigen Zustands für letztgenannte Zelle, um die Schaltung des Originalmoduls in operativer

Hinsicht zu bewahren; und

e. Erzeugung geeigneter Programmieranweisungen, um eine entsprechende Änderung in dem Speicher zu veranlassen, in dem die Zustände der Zellen in dem alten Modul und die Zustände der Zellen in dem reflektierten Modul abgelegt sind.

10. Ein Verfahren zur Erzeugung von Programmieranweisungen, um ein Schaltungsmodul, das in einem Satz programmierter Zellen innerhalb einer Matrix wie in Anspruch 1 spezifiziert verkörpert ist, um neunzig Grad gegen den Uhrzeigersinn zu drehen, wobei das so zu reflektierende Modul "Originalmodul" und das Modul nach erfolgter Drehung "rotiertes Modul" bezeichnet wird, gekennzeichnet durch die nachgenannten Verfahrensschritte:

a. Initialisierung der Lage und der Dimension des rotierten Moduls so, daß die Spalte ganz links in dem Originalmodul die Spalte ganz links der Ausgangslage des rotierten Moduls wird und die oberste Zeile des Originalmoduls die oberste Zelle der Ausgangslage des rotierten Moduls wird, die Breite des Originalmoduls die Länge des rotierten Moduls wird und die Länge des rotierten Moduls die Breite des rotierten Moduls wird;

b. für den Fall, daß die horizontale Parität des Originalmoduls der vertikalen Parität des Originalmoduls entspricht, Verschiebung der Lage des rotierten Moduls um eine ungerade Anzahl von Zellen in waagerechter Richtung;

c. für den Fall, daß die horizontale Parität des Originalmoduls von der vertikalen Parität der Spalte ganz rechts des Originalmoduls abweicht, Verschiebung der Lage des rotierten Moduls um eine ungerade Anzahl von Zellen in senkrechter Richtung;

d. Abbildung einer jeden Zelle des Originalmoduls auf einer Zelle an einer entsprechenden Stelle in dem rotierten Modul und Auswahl eines richtigen Zustands für letztgenannte Zelle, um die Schaltung des Originalmoduls in operativer Hinsicht zu bewahren; und

e. Erzeugung geeigneter Programmieranweisungen, um eine entsprechende Änderung in dem Speicher zu veranlassen, in dem die Zustände der Zellen in dem Originalmodul und die Zustände der Zellen in dem reflektierten Modul abgelegt sind.



## Revendications

1. Appareil numérique contenant une matrice de cellules logiques programmables, la matrice comprenant :
  - a. plusieurs cellules logiques programmables fonctionnellement identiques, ayant chacune plusieurs entrées de signaux et plusieurs sorties de signaux et programmables afin qu'elles prennent l'un de plusieurs états disponibles, 5
  - b. les cellules étant disposées pendant le fonctionnement avec une topologie formant une matrice de lignes et de colonnes de cellules afin que chaque cellule, sauf celles de la périphérie de la matrice, possède quatre cellules voisines immédiates, et 10
  - c. chacune des cellules étant disposée avec l'une de plusieurs orientations distinctes possibles de cellule, les orientations étant liées de manière qu'une orientation de cellule quelconque puisse être obtenue à partir d'une autre orientation quelconque de cellule par une opération choisie parmi une réflexion, une rotation et une rotation suivie d'une réflexion, la matrice contenant au moins une cellule ayant chacune des orientations, caractérisé en ce que chacune des cellules a une orientation différente de celles des cellules immédiatement voisines. 15
2. Appareil selon la revendication 1, dans lequel chaque cellule a deux entrées et deux sorties, et les quatre cellules voisines les plus proches de chaque cellule, sauf celles de la périphérie de la matrice, peuvent être désignées comme étant des voisins Nord, Est, Sud et Ouest, et l'appareil est en outre caractérisé en ce que chaque matrice contient des cellules dans chacune des quatre orientations, une première orientation étant telle que les deux entrées de la cellule sont connectées aux sorties de ses voisins Nord et Sud, une seconde orientation étant telle que les deux entrées de la cellule sont connectées aux sorties de ses voisins Nord et Ouest, une troisième orientation étant telle que les deux entrées de la cellule sont connectées aux sorties de ses voisins Sud et Est, et une quatrième orientation étant telle que les deux entrées de la cellule sont connectées aux sorties de ses voisins Sud et Ouest. 20
3. Appareil selon la revendication 1, caractérisé en outre en ce que chacun des états disponibles de la cellule possède exactement un axe de symétrie. 25
4. Appareil selon la revendication 1, caractérisé en outre en ce que les états disponibles de la cellule ont une propriété telle que, pour chaque état disponible de la cellule, si la première et la seconde entrée de la cellule sont échangées et si la première et la seconde sortie de la cellule sont échangées, l'état résultant de la cellule est l'un des états disponibles de la cellule. 30
5. Appareil selon la revendication 1, caractérisé en outre en ce que les états disponibles comprennent au moins un état dans lequel la cellule transmet une valeur logique constante à l'une de ses sorties. 35
6. Appareil selon la revendication 1, caractérisé en outre en ce que
  - a. les états disponibles de la cellule comprennent un état dans lequel l'une des première et seconde entrées de la cellule est connectée comme identité logique ou négation logique à l'une des première et seconde sortie, et 40
  - b. les états disponibles de la cellule comprennent un état dans lequel l'autre des première et seconde entrées de la cellule est connectée comme identité logique ou négation logique à l'autre des première et seconde sorties. 45
7. Appareil selon la revendication 1, caractérisé en outre en ce que les états de la cellule comprennent des états donnant des fonctions booléennes des entrées de signaux à partir desquelles une fonction logique booléenne universelle peut être assemblée. 50
8. Procédé de création d'instructions de programmation destiné à refléter autour d'un axe horizontal un module de circuit incorporé dans un ensemble de cellules programmées dans une matrice telle que spécifiée dans la revendication 1, le module qui doit être reflété étant appelé "module original" et le module après réflexion étant appelé "module réfléchi", le procédé étant caractérisé par les étapes suivantes :
  - a. la détermination, dans la matrice, de coordonnées, d'un emplacement provisoire pour le module réfléchi, afin que la ligne supérieure de cellules du module réfléchi coïncide avec la ligne supérieure de cellules du module original, et que la colonne la plus à gauche dans le module réfléchi coïncide avec la colonne la plus à gauche dans le module original, 55



b. le décalage de l'emplacement provisoire du module réfléchi d'un nombre impair de cellules en direction verticale afin que la parité horizontale du module réfléchi soit convenable,

c. si le module couvre un nombre pair de cellules en direction horizontale, le décalage de l'emplacement provisoire d'un nombre impair de cellules en direction horizontale,

d. la projection de chaque cellule du module original sur une cellule placée dans le module reflété et la sélection d'un état convenable pour la dernière cellule afin que le circuit du module original soit préservé pendant le fonctionnement, et

e. la création d'instructions convenables de programmation destinées à provoquer un changement correspondant dans la mémoire qui conserve les états des cellules dans l'ancien module et les états des cellules dans le module reflété.

9. Procédé de création d'instructions de programmation destiné à refléter autour d'un axe horizontal un module de circuit incorporé dans un ensemble de cellules programmées dans une matrice telle que spécifiée dans la revendication 1, le module qui doit être reflété étant appelé "module original" et le module après réflexion étant appelé "module reflété", le procédé étant caractérisé par les étapes suivantes :

a. la détermination, dans la matrice, de coordonnées d'un emplacement provisoire du module reflété, afin que la ligne supérieure de cellules du module reflété coïncide avec la ligne supérieure de cellules du module original et que la colonne la plus à gauche du module reflété coïncide avec la colonne la plus à gauche du module original,

b. le décalage de l'emplacement provisoire du module reflété d'un nombre impair de cellules en direction horizontale afin que la parité verticale du module reflété soit convenable,

c. si le module recouvre un nombre pair de cellules en direction verticale, le décalage, de l'emplacement provisoire d'un nombre impair de cellules en direction verticale,

d. la projection de chaque cellule du module original sur une cellule placée dans le module reflété et la sélection d'un état convenable pour cette dernière cellule afin que le circuit du module original soit préservé pendant le fonctionnement, et

e. la création d'instructions convenables de programmation de manière qu'elles provo-

quent un changement correspondant de la mémoire qui conserve les états des cellules dans l'ancien module et les états des cellules dans le module reflété.

10. Procédé de création d'instructions de programmation destiné à faire tourner de 90° dans le sens contraire des aiguilles d'une montre un module de circuit incorporé dans un ensemble de cellules programmées dans une matrice telle que spécifiée dans la revendication 1, le module qui doit être reflété étant appelé "module original" et le module après rotation étant appelé "module qui a tourné", le procédé étant caractérisé par les étapes suivantes :

a. l'initialisation d'un emplacement et des dimensions du module qui a tourné de manière que la colonne la plus à gauche du module original devienne la colonne la plus à gauche de l'emplacement initial du module qui a tourné et que la ligne supérieure du module original devienne la ligne supérieure d'un emplacement initial du module qui a tourné, la largeur du module original devenant la longueur du module qui a tourné, et la longueur du module qui a tourné devenant la largeur du module qui a tourné,

b. si la parité horizontale du module original est la même que la parité verticale du module original, le décalage de l'emplacement du module qui a tourné d'un nombre impair de cellules en direction horizontale,

c. si la parité horizontale du module original diffère de la parité verticale de la colonne la plus à droite du module original, le décalage de l'emplacement du module qui a tourné d'un nombre impair de cellules en direction verticale,

d. la projection de chaque cellule du module original sur une cellule d'un emplacement correspondant dans le module qui a tourné et la sélection d'un état convenable pour cette dernière cellule afin que le circuit de module original soit préservé pendant le fonctionnement, et

e. la création d'instructions convenables de programmation afin qu'un changement correspondant dans la mémoire soit provoqué et garde les états des cellules dans le module original et les états des cellules dans le module reflété.

