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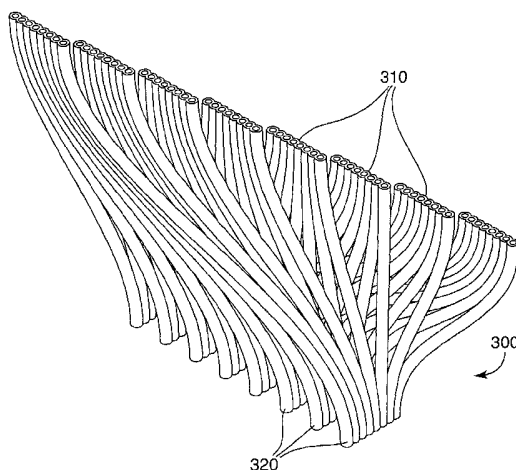
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(54) Title: IN-LINE SHUFFLE MODULES UTILIZING THREE DIMENSIONAL OPTICAL CIRCUITS



(57) Abstract: A three dimensional optical circuit featuring an optical manifold for organizing, guiding and protecting individual optical fibers is shown. One aspect of the present invention is a three dimensional manifold that may be constructed using a rapid prototyping process such as stereolithography, fused deposition modeling, selective laser sintering, and the like. The manifold has a number of input openings in a first ordered arrangement at one end connected by passageways to a number of output openings in a second ordered arrangement at the opposite end. A plurality of optical fibers may be directed through the passageways to produce a three dimensional optical circuit such as a shuffle. The optical manifold may be used in conjunction with a number of connections or terminations to form a various optical modules.

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## **IN-LINE SHUFFLE MODULES UTILIZING THREE DIMENSIONAL OPTICAL CIRCUITS**

### **BACKGROUND OF THE INVENTION**

#### Field of the Invention

5           The present invention relates generally to three dimensional optical circuits and, more particularly, to an optical shuffle module comprising an optical manifold and a method for making the same.

#### Background of the Invention

10           Optical fiber networks are becoming increasingly common in modern telecommunications systems, high speed routers, computer systems and other systems for managing large volumes of data. Optical fiber networks typically comprise a large number of optical fibers which are routed over relatively long distances in order to increase transmission speeds and efficiencies relative to the propagation of conventional electrical signals. There is often the need to route individual optical fibers between  
15           various connection points throughout a system creating an "optical circuit". One of the more common optical circuits in use today is referred to as an "optical shuffle". By way of example only, a simple optical shuffle may be carried out using eight optical fiber cables each having eight individual optical fibers enclosed therein. In what may be referred to as a "perfect shuffle", using the fibers of our example here, fiber 1 of each of  
20           the eight cables coming in may be routed to a single first cable going out, and the second fiber of each of the eight cables coming in may be routed to a single second cable going out, and so forth. Referring now to Figure 1, this particular optical shuffle is represented in a simplified schematic in which  $C_m$  refers to the input ribbon or cable,  $C_m F_n$  refers to the individual fibers  $F_n$  which originate in cable  $C_m$ , and  $C_m'$  is the output ribbon or cable  
25           following the optical shuffle. It is to be understood, that although this particular example featured only 64 optical fibers, optical circuits often involve a far larger number of fibers which must be routed. Therefore, creating optical shuffles and other optical circuit structures by hand can be a tedious and highly error prone process. One can easily envision the nest of tangled optical fibers occurring in circuits between the input cables  
30           and the output cables.

Several solutions have been proposed for the creation of various optical circuits rather than simply trying to route fibers from input points to output points by hand through a large tangle of other fibers. One such solution is the use of semiautomatic machines which weave the individual fibers into the needed circuit arrangement. This solution often  
5 requires a significant financial investment in machines which are of little or no use in applications other than the weaving of optical fibers.

Another solution to the problem of creating optical circuits includes a number of attempts to route optical fibers on a flexible polymer substrate. By way of example only, one popular form of this construct is marketed as a Flex Foil®. One such approach to a  
10 flexible optical circuit solution is set forth and described in U.S. Patent No. 5,204,925 issued to Bonanni *et al.* This reference describes a solution in which a flexible polymer substrate such as Mylar® or Kapton® may be coated with a pressure sensitive adhesive (PSA) and have optical fibers mounted thereon. After a number of optical fibers are laid on the substrate in the proper arrangement, a protective cover layer, usually of the same  
15 type of material as the substrate, can be bonded on top of the fibers. Of course, the exposed surface of this cover layer may subsequently be coated with an adhesive itself and additional layers of optical fibers and cover materials may be built up in the form of a laminate structure. However, the fiber lay-up process is quite labor intensive and, much like fiber weaving, would require highly specialized equipment to automate. Bonanni *et al.* further discloses the use of flexible side tabs or thinner strips of substrate material  
20 which extend laterally from the main body where the shuffle has occurred, and permit the optical fibers to be bent or rotated at, for example, a 90° angle to reorient the fibers from a horizontal position to a vertical position.

Another approach which incorporates a flexible optical circuit is set forth in U.S.  
25 Patent No. 6,005,991 issued to Knasel. This particular reference discloses a printed circuit board (PCB) assembly that includes an interior portion upon which a flexible optical circuit is mounted. Much like the Bonanni *et al.* reference, Knasel arranges a plurality of optical fibers which are sandwiched between flexible sheets. These flexible sheets are commonly formed of Mylar® or the like and hold the optical fibers in place and are  
30 subsequently bonded to other flexible sheets using pressure sensitive adhesives, as known in the art. In this reference, space is conserved along the edge of a printed circuit board by attaching a multifiber connector to the respective first ends of the optical fibers and using

single fiber connectors at the second ends of the optical fibers where space is more readily available, such as the less populated interior portion of the printed circuit board.

It should also be noted that both of these flexible circuit approaches are generally implemented in the form of large sheets with prerouted fiber networks or printed circuit boards with flexible optical circuit portions mounted thereon. In either case, these circuits normally have splices at both the input and output ends of the optical circuit to facilitate attachment to the input fiber cables and the output fiber cables during installation. Splices are normally required to overcome the length limitations of the tabs extending from the body of the flexible circuit. Additionally, splices may be used to attach specialized connectors to the input and output ends of the circuit for coupling to ruggedized cables. The splices at both the input and output end of the shuffle or optical circuit produce optical signal losses which when added across an entire optical network may be significant and unacceptable to the user. Furthermore, both mechanical and fusion splices commonly require considerable amounts of space because of the need to mechanically reinforce or strengthen the splice. Additionally, the flexible optical circuit approaches described here generally do not permit the use of protectively sheathed or "ruggedized" fiber optic ribbons leading all the way up to the flexible circuit, nor do they offer much protection to the optical fibers within the circuit or shuffle beyond the meager protection provided by a single layer of polymer film. Moreover, flexible optical circuit designs do not isolate and protect the individual fibers in that, at crossing points within the circuit, many of these fibers are in direct contact with each other.

Therefore, there is a need for three dimensional optical circuits which can be created without the expense of weaving machines and which can be more readily routed into a number of different shuffle arrangements. There is a need for an optical circuit arrangement which is less labor intensive than building up a multilayer laminate structure of polymer films, various adhesives and optical fibers, several strands of optical fiber at a time. There is also a need for an optical circuit which allows ruggedized ribbons of fiber optic cable to be run up to the circuit and away from the circuit and which provides a ruggedized protected environment for the optical fibers during the shuffle itself. There is a need for a three dimensional optical circuit having fewer fiber splices and reduced optical signal loss. Additionally, there is a need for a three dimensional optical circuit which fits

into environments with limited surface area (x-y axes) by more efficiently stacking the shuffle to fully utilize space in a vertical direction (z-axis).

### **SUMMARY OF THE INVENTION**

The three dimensional optical fiber circuit apparatus and method described herein  
5 below will address each of these aforementioned needs and provide a number of additional benefits as well. In one embodiment, the present invention is a rigid, unitary, three dimensional manifold constructed using a rapid prototyping process such as, but not limited to, stereolithography ("SLA"), fused deposition modeling ("FDM"), selective laser sintering ("SLS"), and the like. Note that the terms rapid prototyping and rapid  
10 manufacturing are interchangeable in regard to the present invention in that this technology may be utilized not only for creating prototypes, but actual manufacturing as well.

Although the equipment for carrying out SLA processes and other rapid prototyping techniques are relatively expensive machines, these systems are general  
15 purpose and are readily available. SLA machines and other rapid prototyping machines are readily programmable to create virtually any three dimensional object which can be designed on a computer aided design ("CAD") system. Accordingly, the design of a three dimensional manifold for routing a large number of optical fibers may be laid out in any number of configurations or arrangements limited only to the capabilities of the CAD  
20 system or the imagination of the designer. Moreover, it is possible to program these systems to create passageways or channels for routing optical fibers to provide for an appropriate bend radius and thereby minimize optical signal loss, and to isolate and protect the individual fibers throughout the optical circuit. Further, it is possible to create optical circuits that could not be readily manufactured using conventional molding or forming  
25 techniques.

The fiber optic manifold, in accordance with the present invention, may take any number of possible embodiments, including a solid block having a number of hollow passageways connecting input points and output points or a large plurality of rigid hollow tubes which again have a number of input points and output points. By way of example  
30 only, these input openings may be arranged in a matrix having an equal number of rows and columns. In the case of 8 fiber optic cables each having 8 fibers, this would require an

optical manifold having 64 input openings, 64 output openings, and 64 passageways connecting therebetween. If the input and output ends of the manifold are properly labeled, it should be relatively easy for a user to determine which optical fiber is to be inserted into the appropriate opening and will exit from the appropriate opening on the opposite end of the manifold. Moreover, since there is only one passageway connecting a particular input with a particular output there is no need to worry about fibers becoming entangled within each other or causing confusion for the person guiding them through the manifold.

In yet another embodiment, the present invention is a process for forming a three dimensional optical circuit including the steps of providing a rigid, unitary optical manifold having an input end and an output end; arranging a plurality of optical fiber cables leading up to the input end of the manifold, and arranging a plurality of optical fiber cables leading away from the output end of the manifold; splitting out the individual fibers of each input cable and guiding each fiber to an individual input opening of the manifold, collecting up the individual fibers extending from the output openings of the optical manifold and gathering them back up into optical cable bundles. Generally, it is possible to merely strip and separate the optical fibers from the input cables and feed them into the input openings of the manifold, passing them through the manifold and then terminating the resulting cable groups at the output side only and have no fiber splices within the shuffle itself. Thus, it is not unreasonable to completely eliminate optical signal losses incurred by splices within individual optical circuits, including shuffles. This reduction in optical signal losses could be quite significant if multiplied throughout an entire optical network.

In a further embodiment, the present invention is a three dimensional optical circuit that has been configured to operate as an in-line shuffle module. Although an optical shuffle module may take a number of different forms, one particularly useful embodiment would be an in-line shuffle configured to fit within the spaces normally allotted for optical fiber bundles in building utility tunnels, electronic equipment housings and the like. One form of shuffle module may be cylindrical in shape with about a one inch diameter and fitted with a number of ruggedized cable attachments at either end. This particular in-line shuffle would receive ruggedized fiber bundles at the input end, shuffle the individual fibers by passing them through a particularly small optical manifold and permit the fibers

to be gathered back into ruggedized fiber bundles at the output end, all within a space commonly allowed for cable trunk lines. Moreover, if the in-line shuffle module were placed in the optical cable during installation, it would be possible to carry out this entire shuffle without a splicing any of the optical fibers.

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### **BRIEF DESCRIPTION OF THE DRAWINGS**

A more complete understanding of the method and apparatus of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying drawings in which like reference numerals refer to like parts and wherein:

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Figure 1 is a simplified schematic representation of a number cables and fibers in a perfect 8x8 optical shuffle;

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Figure 2 is a perspective view of an optical manifold constructed in accordance with one embodiment of the present invention and featuring cross bracing members to ensure proper spacing and structural rigidity between the various rows and columns of the input ends and output ends of the optical manifold;

Figure 3 is a perspective view of an optical manifold constructed in accordance with another embodiment of the present invention featuring staggered side-by-side inputs and stacked outputs;

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Figure 4 is a perspective view of the optical manifold in accordance with the embodiment of Figure 3 featuring ruggedized cable attachments for receiving ruggedized cables at one end of the manifold;

Figure 5 is a detailed perspective view showing the interior structure of a pitch tool aligned with the optical manifold of Figure 4.

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Figure 6 is a perspective view of the optical manifold in accordance with the embodiment of Figure 3, featuring ruggedized cable attachments at both the input and output ends of the optical manifold;

Figure 7 is a perspective view of an optical manifold in accordance with yet another embodiment of the present invention, further incorporating an input endplate, an output endplate and mounting brackets.

Figure 8 is a bottom view of the optical manifold in accordance with the embodiment of Figure 7 and clearly showing the four mounting holes located near the corners of the manifold;

5 Figure 9 is a side elevational view of the optical manifold in accordance with the embodiment of Figure 7 featuring integral endplates at both input and output ends;

Figure 10 is a detailed perspective view of the optical manifold in accordance with the embodiment of Figure 7, featuring the input endplate and the ribbon and fiber numbering system;

10 Figure 11 is a detailed perspective view of the optical manifold in accordance with the embodiment of Figure 7, featuring the output endplate and the ribbon and fiber numbering system;

Figure 12 is an exploded perspective view of an optical manifold constructed in accordance with the present invention by stacking a series of plates having inscribed grooves or channels;

15 Figure 13 is an exploded perspective view of an alternative embodiment optical manifold to that shown in Figure 12 constructed by stacking a series of plates having inscribed grooves or channels;

20 Figure 14 is an exploded perspective view of an optical manifold constructed in accordance with the present invention by stacking a series of plates having a plurality of fiber guide pieces affixed to a surface to form grooves or channels;

Figure 15 is an exploded perspective view of an alternative embodiment optical manifold to that shown in Figure 14 constructed by stacking a series of plates having a plurality of fiber guide pieces affixed to a surface to form grooves or channels;

25 Figure 16 is a perspective view of a three dimensional optical circuit constructed in accordance with the present invention in which the optical manifold has been enclosed within a protective housing and mounted on a plug-in card;

Figure 17 is an exploded perspective view of a three dimensional optical circuit constructed in accordance with the present invention in which a ruggedized optical cable is coupled to a ruggedized cable attachment on the optical manifold;

30 Figure 18 is an exploded perspective view of a three dimensional optical circuit constructed in accordance with the present invention and illustrating a shuffling connector with ferrule spring, push-pin connectors;

Figure 19 is an assembled perspective view of the three dimension optical circuit shown in Figure 18 and illustrating a shuffling connector with ferrule spring, push-pin connectors;

Figure 20 is a perspective view of a three dimensional optical circuit constructed in accordance with the present invention and illustrating an integrated shuffle module with ruggedized fiber inputs, bulkhead connector outputs, and an enclosure suitable for rack mounting;

Figure 21 is a perspective view of a 64 fiber compact shuffle manifold, which incorporates a scheme or formula for routing fibers similar to that of the embodiment shown in Figure 7, but in an entirely different physical configuration;

Figure 22 is an end-on view of the compact shuffle manifold of Figure 21 showing representative dimensions for 30 mm minimum bend radius fibers;

Figure 23 is a top plan view of the compact shuffle manifold of Figure 21 showing representative dimensions for 30 mm minimum bend radius fibers;

Figure 24 is a top plan view of the compact shuffle manifold of Figure 21 showing representative dimensions for 10 mm minimum bend radius fibers;

Figure 25 is a perspective view of a simple tube shuffle module providing a housing about the compact shuffle manifold of Figure 21;

Figure 26 is an exploded perspective view of the simple tube shuffle module of Figure 25;

Figure 27 is a perspective view of a ruggedized cylindrical shuffle module providing a housing about the compact shuffle manifold of Figure 21;

Figure 28 is an exploded perspective view of the ruggedized cylindrical shuffle module of Figure 27;

Figure 29 is a perspective view of a hinged, ruggedized cylindrical shuffle module providing a housing about the compact shuffle manifold of Figure 21.

Figure 30 is an exploded perspective view of the hinged, ruggedized cylindrical shuffle module of Figure 29;

Figure 31 is an end-on view of the hinged, ruggedized cylindrical shuffle module of Figure 29 with the hinged portions opened to show interior details;

Figure 32 is a perspective view of a one-side ruggedized shuffle module providing a housing about the compact shuffle manifold of Figure 21; and

Figure 33 is a partially exploded perspective view of the one-side ruggedized shuffle module of Figure 32 with the top cover removed to show interior details.

### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

Referring now to the Figures, and in particular to Figures 2-6, there is disclosed a number of embodiments or variations constructed in accordance with the present invention for providing an optical manifold which may be incorporated into a three dimensional optical circuit such as a shuffle. As used herein, the term "optical manifold" shall refer to a component of a three dimensional optical circuit which provides a number of passageways for connecting a set of input openings to a set of output openings and for receiving a plurality of optical fibers in a first ordered arrangement at the input and outputting the plurality of fibers in a second ordered arrangement at the exit. As used in regard to the openings of an optical manifold, the term "ordered arrangement" refers not to the actual spatial relationship or location of one hole relative to another, but rather to the relationship of an input opening to an output opening.

By way of example only, an optical manifold for carrying out a perfect shuffle, as described in regard to Figure 1, may have a first ordered relationship in which the holes of row 1 correspond to fibers 1-8 of cable 1, the holes of row 2 correspond to fibers 1-8 of cable 2, and so forth. For this particular shuffle, the holes at the output end of the manifold may have a second ordered relationship in which the holes in row 1 correspond to fiber 1 of cables 1-8, the holes of row 2 correspond to fiber 2 of cables 1-8, and so forth. Thus, even though the holes at both ends of the manifold are disposed in an 8x8 array the ordered relationship of one hole to another at the input may be quite different from the ordered relationship at the output. In other words, by merely shifting the positions, relative to each other, of at least two fibers passing through an optical manifold, the ordered relationship of holes at the input end and output end of the manifold must be different.

Individual optical fibers may be split out of optical cables, guided through the optical manifold, and subsequently interfaced with another optical fiber, an optical connector, an optical waveguide or nearly any other optical device. It should be further noted that, although each of the examples shown and described herein involve the use of 8 optical cables, each containing 8 optical fibers, for a total of 64 individual optical fibers,

these optical circuits may involve larger or smaller numbers of cables and fibers limited only by the imagination of the designer, the limitations of the CAD system and the physical limitations of the stereolithography or other rapid prototyping machines. Of course, fibers are most commonly bundled in multiples of 4 to produce cables having, for example, 8, 12, 16 or 24 fibers each. It should also be noted that, although in the examples shown herein the optical fiber manifolds are constructed of various UV curable photopolymers, as known in the art, it is also possible to utilize rapid prototyping techniques with various ceramic and metal compounds as well.

A fairly common optical circuit is that of a perfect shuffle which is carried out by inputting the individual fibers corresponding to row 1, columns 1-8 and routing them to column 1, rows 1-8, inputting the optical fibers of row 2, columns 1-8 and routing them to column 2, rows 1-8 and so forth. Of course, as will be illustrated in Figures 7-11, it is also possible to also arrange the fibers using an imperfect shuffle arrangement in which the fibers of row N are each advanced by N-1 number of columns from the input to the output end of the manifold. For example, in row 1 the fiber corresponding to column 1 at the input will exit at column 1. The fiber corresponding to column 2 at the input will exit at column 2 and so forth, with the fiber at input column 8 exiting at output column 8. In row 2, the fiber at input column 1 will exit at output column 2, the fiber at input column 2 will exit at column 3, and so forth with the fiber from input column 8 exiting at output column 1. Again, it is to be understood that these imperfect shuffles may be arranged in any number of ways (*e.g.*, N+1, N-2, or the like), limited only by the CAD systems and rapid prototyping machinery used. One preferred form of rapid prototyping discussed herein is stereolithography, and although this is not the primary focus of the present invention, it is worth noting in some detail how a part is generally produced using stereolithography techniques.

Rapid prototyping is the name given to a host of related technologies that are commonly used to fabricate three dimensional physical objects directly from CAD data sources. These methods are generally similar to each other in that they normally create a three dimensional object by building up materials in a layer-wise fashion. Rapid prototyping is also referred to by the name of free form fabrication ("FFF"), layered manufacturing, automated fabrication and other variations of these terms. Stereolithography ("SLA") is the most commonly used rapid prototyping technology.

This technique creates three dimensional plastic parts or objects one layer at a time by tracing or rasterizing a laser beam on the surface of a liquid photopolymer. This specialized class of polymer materials quickly solidifies wherever the laser beam strikes the surface of the liquid. Once one layer of the object is completely traced, the object is lowered one layer thickness on a stage into a container filled with photopolymeric material and a second layer is then traced by the laser right on top of the first. The photopolymer is self-adhesive in nature and the layers tend to bond one to another as they are built up to form a three dimensional object. Following the creation of the three dimensional part, it may be removed from the stereolithography apparatus and placed in an ultraviolet ("UV") post-curing, oven-like apparatus for a more complete cure and added dimensional stability.

The technique of selective laser sintering is somewhat similar to stereolithography in that the object is built up one layer at a time using a laser tracing a pattern on the surface. However, the polymer or other material is usually in powder form and is heated and fused together by the laser which melts the powder where it strikes under the guidance of a scanning system. Regardless of the rapid prototyping technique used, following curing, the resulting three dimensional object is a single, unitary and integral part and requires little, if any, further machining to produce a finished product. In the case of the various embodiments of the present invention, these three dimensional parts may be referred to as optical manifolds and may be laid out in any number of geometries or arrangements but will feature a number of hollow passageways, tubes or channels for routing individual optical fibers each from a single input opening to a single output opening of the manifold. The manifold has the additional benefit of being quite rigid and tough enough to protect the optical fibers from various environmental conditions and hazards that may be encountered.

Referring now to Figure 2, a perspective view of a stacked eight by eight shuffle manifold 200 is shown. As shown here, the input openings 210 and the output openings 220 are arranged in an 8x8 matrix with each of the columns of the input end and rows of the output end arranged in a stacked configuration with support members 230 disposed therebetween. The support members 230 serve to ensure proper spacing of the columns and rows, and also to provide additional strength and rigidity to the finished part. When filled with optical fibers, not shown, this particular embodiment produces a perfect shuffle in that the individual fibers of row 1 from columns 1-8 are brought together in column 1,

rows 1-8 of the output end. The fibers of input row 2, columns 1-8 are shuffled to be arranged in column 2, rows 1-8 of the output end and so forth, with the fibers of row 8, columns 1-8 being shuffled into column 8, rows 1-8 of the output end of the manifold. It is to be noted that the CAD system has been programmed to ensure that none of the individual fibers are forced to experience a bend tighter than the critical bend radius, thereby minimizing optical signal loss and maximizing mechanical life span for each of the fibers passing through the optical manifold.

Referring now to Figure 3, another embodiment of an optical manifold 300 constructed in accordance with the present invention is shown. In this particular design, the input openings 310 and the output openings 320 of the manifold 300 are again stacked one on top of the other or side-by-side with each other, but the support members disposed therebetween have been removed. Additionally, at the input end of the manifold 300 columns 1-8 have been staggered side-by-side to provide additional spacing between each set of input openings 310.

Referring now to Figure 4, a manifold 400 constructed in accordance with the embodiment illustrated in Figure 3 has been modified by the addition of a number of ruggedized cable attachments 450, leading to the input openings 410 of the manifold 400. This manifold 400 is suitable for receiving up to eight ruggedized fiber optic cables, not shown. Each of these cables will have a snap-fit member that may be coupled to the cable attachments 450 and then subsequently routed through the optical manifold 400. The term "ruggedized" cable generally refers to a type of optical cable with a tough polymer exterior which may be further reinforced by the use of Kevlar® or other internal tension-bearing members. Cables such as these provide the optical fibers with a great deal of physical and mechanical protection from harsh external environments.

Referring now to Figure 5, a detailed illustration of a multifiber pitch tool 500 is shown. This tool is designed to receive fibers 100 having ribbon spacing or ribbon pitch and to split out or spread the individual fibers of each cable before entering the optical manifold 400. The multifiber pitch tool 500 ensures the proper spacing and alignment of the fibers with the input openings of the manifold 410.

Of course, it is also possible to use this same form of ruggedized cable attachments at the output openings of the manifold to gather individual fibers into cable bundles, as shown in Figure 6. Referring now to Figure 6, yet another variation of the embodiment

shown in Figure 3 is illustrated. In this particular optical manifold 600, ruggedized cable attachments 650 have been provided at both the input 610 and output 620 ends of the manifold 600.

Referring now to Figures 7-11, and in particular to Figure 7, a perspective view of an imperfect shuffle featuring an input endplate and an output endplate as well as openings for screws or other mounting hardware is shown. Note that in this particular optical manifold 700 embodiment the input rows are numbered 1-8 from the bottom to the top and the input columns are numbered 1-8 from left to right. As described earlier, the individual fibers of this imperfect shuffle are rearranged in a stepwise fashion. The formula for this shuffle is for row N move the fiber N-1 columns over. Thus, the fibers in row 1, columns 1-8 correlate to output row 1, columns 1-8 without any movement. The individual fibers of input row 2, columns 1-8 correspond to output row 2 with columns shuffled one step in which the input of column 1 corresponds to the output of column 2, the input of column 2 corresponds to the output of column 3 and so forth with the input of column 8 corresponding to the output of column 1. Likewise, in row 3, the input of column 1 corresponds to the output of column 3, the input of column 2 corresponds to the output of column 4, and so forth, until the input of column 8 corresponds to the output of column 2. This progression is carried on through row 8, in which column 1 corresponds to output column 8, input column 2 corresponds to output column 1 and so forth with input column 8 corresponding to output column 7.

Referring now to Figure 8, a bottom view of the optical fiber manifold 700 of Figure 7 is shown. From this view it is possible to observe how the 64 individual fiber tubes are arranged to ensure that the fibers do not go beneath the minimum bend radius and that, because they are enclosed in individual tubes, the individual fibers may be very densely overlapped without worry of entanglement. Additionally, this figure shows the input endplate 705, the output endplate 715 and the holes 730 extending through the entire depth of the object for screws or other mounting hardware. It should be noted that the manifold 700 may be mounted in any number of systems or configurations, as well as attached to a removable card, much like a printed circuit board, as known in the art. Additionally, although this manifold 700 is shown without any sort of connectors or terminations at the input 710 or output 720 end, it is to be understood that multifiber attachments or individual fiber connections or terminations may be used at the input and

output ends of the manifold 700, much like those illustrated in Figures 4 and 6. Figure 8, further illustrates a significant number of free spaces or openings provided between the tubes or passageways of the optical manifold. These free spaces may also be particularly useful in rack mounting applications in that the spaces permit cooling airflow for heat generating components to pass completely through the manifold.

Referring now to Figure 9, a side elevational view of the manifold of Figure 7 is shown. This figure best illustrates the stacked vertical arrangement of each of the layers of individual tubes, channels or passageways that make up the manifold 700. As a result of the rapid prototyping techniques used, it is possible to achieve an incredibly compact and efficient design without fear of fiber entanglement or significant optical signal loss. Rapid prototyping also allows adjacent passageways or tubes to share a common sidewall. Accordingly, a manifold 700 produced in accordance with the present invention will be far more compact than a collection of preformed tubes that have been brought together to form a manifold.

Referring now to Figure 10, an enlarged perspective view of the manifold of Figure 7 is shown. Here, the input end 710 of the manifold 700 is clearly illustrated indicating markings for a user to identify the ribbon or cable numbers from 1 to 8 and the individual fibers that make up those cables, again from 1 to 8 at the input end. Of course, the rows and columns of the manifold may be labeled or color-coded in almost any manner which facilitates proper identification.

Referring now to Figure 11, another enlarged perspective drawing of the manifold embodiment shown in Figure 7. This particular figure best illustrates the output end 720 of the manifold 700 again featuring a numbering guide for users illustrating the ribbon or cable numbers from 8 to 1 and the fiber numbers ranging from 1 to 8. It is believed that one of the unique benefits of the present invention is that it facilitates a shuffle of any number of mathematical arrangements in a nearly error proof manner by merely feeding the properly numbered or color-coded fiber of each input cable and then collecting the fibers into the appropriate output cables at the opposite end of the manifold. In short, as long as the appropriate fibers are fed into the proper input holes, they must emerge at the appropriate output holes of the manifold and be collected into the appropriate multifiber cables or bundles.

Referring now to Figure 12, another alternative embodiment constructed in accordance with the present invention is shown. The body of an optical manifold 800 may be constructed by building up a series of stacked plates 810. Each of these plates 810 will have a number of grooves or channels 820 extending completely across its length from the input end 830 to the output end 840 of the plate 810. As the plates 810 are indexed to align the edges and stacked to form an optical manifold 800, the channels 820 in each plate 810 act as passageways connecting input openings at one end of the manifold 800 with output openings at the opposite end of the manifold. Of course, these plates may be manufactured by a number of different techniques including, but not limited to, milling channels into a solid plate, molding the plate with channels on a surface, or building the plate up in a layer additive process such as those described hereinabove.

Referring now to Figure 13, an alternative embodiment of the optical manifold set forth and described in regard to Figure 12 is shown. As in the embodiment of Figure 12, the body of an optical manifold 900 may be constructed by building up a series of stacked plates 910 in which each of these plates has a number of grooves or channels 920 extending completely across its length from the input end 930 to the output end 940 of the plate 910. However, in this particular embodiment, the channels or grooves 920 are arranged on each plate to avoid any intersections. This may be done to prevent fibers from coming in direct contact with each other or being possibly misdirected into the wrong channel 920 while passing from the input end 930 to the output end 940 of the manifold 900. As shown here, a manifold constructed in this manner will require at least twice the number of grooved plates 910 to facilitate the same optical circuit constructed from plates which allow the channels to intersect and the fibers to touch. This also results in a stacked plate manifold which is much taller or larger in the z-direction than the embodiment depicted in Figure 12.

Referring now to Figures 14 and 15, a manufacturing variation of the stacked plate manifolds shown in Figures 12 and 13, respectively, is shown. The manifold embodiments 800', 900' as shown in Figures 14 and 15 are again created by stacking plates 810', 910' one on top of another and indexing them to form a manifold. However, the embodiments of Figures 14 and 15 do not have channels or grooves 820', 920' which are milled, cut or molded into the plates, but rather a large number of individual guide pieces 850', 950' which are glued, affixed or attached in some manner to a particular plate 810',

910' to create a pattern thereon. As one skilled in the art will recognize, the labor or manufacturing steps required to produce a large number of guide pieces, attach them to their respective plates, and then stack the plates one on top of another to form a manifold would be considerable, particularly in comparison to plates formed by milling, injection molding, or other production techniques. Figures 14 and 15 are provided to show yet another approach to creating a stacked plate manifold as depicted in Figures 12 and 13.

Referring now to Figure 16, a perspective view of an optical manifold that has been enclosed within a protective housing 1010 and mounted on a plug-in card 1020 is shown. This embodiment may also be referred to as a plug-in optical shuffle module 1000. As shown here, ruggedized and ribbonized optical cables 50 are directed to multifiber attachments 1050 and the unterminated fiber ends are inputted to an optical shuffle in accordance with the present invention. The optical manifold is enclosed within a protective housing 1010 of molded polymer, formed sheet metal embedded in epoxy or the like. Following the shuffle, the individual fibers are again gathered into ribbonized bundles 60 and directed to blind-mate, plug-in or other optical card connectors 1060. These connectors 1060 serve as terminations that are adapted to allow fiber connections at the edge of the plug-in card 1020 and allow the optical shuffle to be implemented in a fully modular quick-connect design.

Referring now to Figure 17, a three dimensional optical circuit 1200 with an exploded detail view of a single ruggedized optical fiber cable 50 attached thereto is shown. The three dimensional optical circuit features an optical manifold 400 similar to that set forth and described in regard to Figure 4. This manifold features eight ruggedized cable attachments 450 at the input end, which are designed to receive a snap fit, crimp barb 1230 to facilitate the transfer of mechanical loads and stresses from the ruggedized exterior of the optical cable 50 through the crimp barb 1230 and into the body of the optical manifold 400 itself. In short, one of the unique and surprising features of an optical circuit utilizing the optical manifold of the present invention is that mechanical loads or stresses may actually be transferred to and carried by the unitary body of the manifold itself. This is quite different from flexible substrate or woven fiber approaches in that the manifold itself can provide stress relief to the fibers which are passing therethrough. It is the inventors' belief that the prior art does not show any sort of

apparatus which could both shuffle or organize optical fibers into a circuit while also carrying a mechanical load or providing stress relief to the fibers themselves.

As shown here, a ruggedized cable 50 containing a number of optical fibers 100 is passed through a manifold 400 by first cutting back the ruggedized exterior portion of the cable 50; passing the exposed fibers 100 through a strain relief boot 1210, a crimp ring 1220 and a crimp barb 1230; crimping the crimp ring 1220 to the load bearing ruggedized exterior of the cable 50; fitting the crimp ring 1220 within the crimp barb 1230 to transfer mechanical stresses from the ruggedized cable 50 to the barb 1230; and finally connecting the barb 1230 to the ruggedized attachment 450 of the manifold 400 to transfer stresses from the cable 50 to the crimp ring 1220 to the crimp barb 1230 to the manifold itself 400. As the optical fibers 100 of the ruggedized cable 50 are passed through the ruggedized attachment 450, they may be spread using a pitch tool or the like to ensure proper alignment with the manifold 400. Finally, the optical fibers 100 are guided and inserted into the appropriate input openings 410 of the optical manifold 400 to create a three dimensional optical circuit.

Referring now to Figure 18, a three dimensional optical circuit constructed for use as a shuffling connector 1400 with ferrule spring, push-pin connectors 1410 is shown. As shown here, a particularly small optical shuffle 1450 may be used to arrange optical fibers 100 into a three dimensional circuit and output the fibers to shuffle adapters 1460 which gather individual fibers 100 back together into bundles or ribbonized form. The ribbonized fiber bundles 60 may then be terminated in a ferrule spring, push-pin type connector 1410 for use with a blind mate card connector 1420, as shown. It is possible to envision a particularly small shuffling connector 1400 such as this fitting within various environments including enclosures for electronics as a sort of optical plug-in card or module. This small, highly efficient modular design is quite different from the significantly greater amounts of surface space required to create optical circuits including shuffles using prior art flexible substrate techniques and optical fiber splices to attach the appropriate connectors.

As best seen in Figure 19, an assembled shuffling connector 1400 may be quite compact in design. This entire modular component may be less than 2.0 inches in both length and width, and less than 1.0 inch in height. For comparison purposes, a flexible substrate optical circuit configured to carry out a similar function, may require 12.0 inches

or more in both the length and width directions, and while being thinner in the z-direction, it is difficult to allow for such large surface areas within the densely packed environment of an electronic enclosure.

Referring now to Figure 20, a perspective view of a three dimensional optical circuit illustrating an integrated shuffle module 1500 having ruggedized fiber inputs 1510, bulkhead connector outputs 1520, and a housing 1550 suitable for rack mounting is shown. The modular design shown here, features a durable housing 1550 suitable for rack mounting within an electronic enclosure. This particular three dimensional optical circuit features an optical manifold 700 of the embodiment shown and described in regard to Figures 7-11. It further includes fiber routing features or fins 1530 for guiding the optical fibers through a safe bend radius within the housing 1550 and toward the optical terminations and bulkhead connectors 1520 provided at the output of the module 1500. It should also be noted that at the input of this module 1500 there are provided ruggedized cable attachments 1510 adapted to receive fibers from ruggedized cables 50, of nearly any length, and for efficiently transmitting mechanical loads and stresses from the ruggedized cables 50 into the body of the housing itself to again provide stress relief for the optical fibers. Although this modular design features one particular form of optical manifold, one skilled in the art will appreciate that virtually any optical manifold, and particularly those created in accordance with the unitary body, rapid prototyping optical manifold embodiments of the present invention.

Referring now to Figures 21-24, and in particular to Figure 21, a perspective view of a 64 fiber imperfect shuffle manifold 1600 which is similar in design to that of Figure 7 is shown. As with the embodiment set forth in Figure 7, the formula for this shuffle is for row N to move the fiber N-1 columns over, thus rearranging the fibers in a stepwise fashion. Note that in this particular optical manifold 1600, a highly compact configuration results from the elimination of free spaces in the embodiment shown in Figure 7 and the elimination of potentially load-bearing end caps. Accordingly, this compact shuffle manifold 1600 is designed to accept loose non-ruggedized fibers at the input end, pass them through a series of tubes or passageways to carry out the shuffle, and exit individual non-ruggedized fibers at the exit. The primary benefit of this compact design is a substantial decrease in the amount of space required to create an optical circuit and carry out a shuffle.

By way of example only, Figures 22 and 23 show an end on view and a top plan view, respectively, of the compact shuffle manifold 1600 of Figure 21 with exemplary dimensions specified on the drawings for use with optical fibers having about a 30 mm minimum bend radius. Although it is possible with conventional optical fibers to attain  
5 minimum bend radius approaching 25 mm, the exemplary manifold 1600 presented in Figures 21-23 configured on a 30 mm minimum bend radius basis is suitable for most applications in small spaces and should also permit a certain factor of safety to ensure adequate mechanical life of the fiber. Smaller bend radii tend to induce larger mechanical strains in optical fibers and may shorten the mechanical life of the fiber.

10 As noted on Figures 22 and 23, the compact shuffle manifold 1600 design shown here has a maximum width of 18.2 mm, a height of 11.8 mm and a total length from input end to output end of 83.4 mm. Accordingly, the embodiment shown here may be configured to fit within housings and other enclosures of less than 1 inch or 25.4 mm in diameter. This is particularly useful in regard to in-line shuffle applications in which it is  
15 desirable to receive input fibers, carry out a shuffle and output the fibers in a space which is scarcely larger than that which is required for the optical fiber bundles themselves. It is common to provide at least a 1 inch diameter area to route optical fibers and other cables within housings for electronic equipment or conduits for running cables throughout buildings and the like.

20 Additionally, as best seen in Figure 24, an even smaller compact shuffle manifold 1700 may be designed for use with low bend radius optical fibers. There has been a drive underway within the optical fibers industry to construct fibers that exhibit tighter bend radii than are currently possible. Although there are a number of approaches being explored to achieve this goal, these types of fibers are being developed to provide low  
25 light loss and high mechanical life when used in applications having small bend radii. When fibers such as these having safe minimum bend radii of about 10 mm become commercially available, it would be possible to reduce the overall length of the compact shuffle manifold 1700 to a mere 52.3 mm. As with the embodiment shown in Figures 21-23, this manifold 1700 is also ideally suited for use in many different in-line applications  
30 and may be particularly well suited for use in board or card type mounting applications where it is to be placed within a crowded environment such as an enclosure for electronic equipment.

With reference now to Figure 25, a perspective view of a simple tube shuffle module 1800 providing a housing about the compact shuffle manifold of Figure 21 is shown. As seen here, this is a rather straightforward embodiment which places a compact shuffle manifold within a cylindrical enclosure 1810 formed of metal, structural polymer, or the like and sealed by endcaps 1820 at the input and output ends.

As best seen in Figure 26, the compact shuffle manifold 1800 may be further provided with cylindrical ribs 1840 along its length and end flanges 1830 to assist in the positioning of the manifold within the simple tube enclosure 1810. As shown in this exploded view, the outer tube 1810 may be slid into place over one end of the manifold 1850 and endcaps 1820 fastened into place using screws 1825, grommets or other suitable fastening means to attach the endcaps 1820 at the input and output ends.

By selecting the appropriate materials for the tube 1810 and endcaps 1820, it is possible to make the housing for the shuffle manifold 1850 extremely durable. For example, a stainless steel tubular shell 1810 would provide a great deal of physical protection to the components inside and have the additional benefit of providing a significant degree of flame resistance under conditions similar to those of the UL-94V0 standard.

One lower cost alternative to a stainless steel or metal housing would be presented by using a tube 1810 and endcaps 1820 formed of specialty polymers which have been treated to achieve an appropriate level of heat and flame resistance. In this type of embodiment, the tube 1810 may be fitted about the components, the endcaps 1820 put in place and the tube 1810 may be heat shrunk or otherwise made to fit snugly about the manifold 1850. In this case, the cylindrical ribs 1840 along the length of the manifold 1850 could also help to maintain a small air gap between the tube 1810 and the manifold 1850 itself providing an additional limited amount of heat insulation. It is also notable that although the simple tube shuffle module 1800 shown in Figures 25 and 26 does not provide a ruggedized environment for the individual optical fibers leading up to and away from the module 1800, it is possible to design the endcaps 1820 to accept various hardware compatible for use with ruggedized cables leading to and from the module 1800, as shown in the other embodiments herein.

With reference now to Figures 27 and 28, one embodiment of an in-line cylindrical shuffle module 1900 for use with ruggedized cables is shown. An in-line shuffle module

1900 such as that shown in Figure 27, may be configured to incorporate the compact shuffle manifold 1950 of Figure 21 and have overall dimensions of about 153 mm in length and an outer diameter of about 25.4 mm. This particular embodiment of the in-line shuffle module 1900 is suitable for use with ruggedized fiber cables at both the input and output ends and easily fits within spaces and access ways of only about 1 inch in diameter.

Referring now to Figure 28, an exploded view of the ruggedized cylindrical shuffle module 1900 is shown. As shown here, a 64 fiber optical manifold 1950 similar to the one set forth and described in regard to Figures 21-23 is located at the center of the module 1900. The compact optical manifold 1950 may be fitted within a shuffle cradle 1920 which helps to secure the manifold 1950 to the tube half bottom 1910 of the ruggedized cylindrical module 1900. A barb keeper 1940 is positioned at the input and output ends of the tube. Each barb keeper 1940 is provided with a spider spring 1945 and designed to receive eight hexcrimp barbs 1960. The spider spring 1945 on each barb keeper 1940 helps to ensure that the hexcrimp barbs 1960 are held securely in place. As shown here, the hexcrimp barbs 1960 are crimp barbs having a hexagonal head resembling a bolt at one end and gradually to taper to a substantially circular opening at the other end. Of course, other forms of crimp barbs, such as those described hereinabove, may also be used. Following the installation and threading of the optical fibers, tube half top cover portions 1930 may be attached to the shuffle cradle 1920 and the barb keepers 1940 to complete the module enclosure.

Still referring to Figure 28, a suggested assembly flow for this type of ruggedized cylindrical module 1900 may be described as follows. An optical cable jumper is made up to the proper length, tested and then cut in half. The heat shrink and crimp tube is then placed on each jumper half. Following the removal of an appropriate amount of the ruggedized jacket from the jumper half, the jacket end is split to accommodate the diameter of the crimp barb 1960. The attachment barb 1965 is crimped onto the end of the jacket. These four steps are then repeated until a sufficient number of jumper halves have been created for the needs of the circuit to be created. In the case of an 8 x 8 shuffle, there should be 4 double length jumpers tested and 8 jumper halves prepared. The operator then places one of the prepared attachment barbs 1960 into the input end of the module 1900 and proceeds to feed all of the fibers into the appropriate input holes of the manifold 1950 for the cable number being sequenced. This step is then repeated until all eight of the

input jumper halves have been processed. The operator then gathers up the appropriate fibers which have now exited the compact shuffle manifold 1950 and gathers them into output barbs at which point the bare fibers may be re-jacketed to complete the output jumper half. This step is then repeated until all eight of the output jumper halves have been completed. Following these steps, the operator then attaches the tube half top covers 1930 to complete the housing and end ring 1970 which may be tightened with screws 1975 or other fasteners about prepared jumper halves to ensure that the crimped jumpers remained securely attached to the input and output barbs of the module. The operator may then complete the output cables with fiber optic terminations appropriate for the final use of the module. In this matter, it is possible to input ruggedized fiber bundle cables, shuffle individual fibers using the manifold contained within the ruggedized cylindrical housing and output ruggedized fiber bundles at the other end.

With reference now to Figures 29-31, a hinged, ruggedized cylindrical shuffle module 2000 is shown. As best seen in Figure 29, the hinged module is similar in shape and overall dimensions to that of the non-hinged ruggedized cylindrical module 1900 set forth and described in regard to Figures 27 and 28. As best seen in Figure 30, the compact shuffle manifold 2050 is enclosed between a half body top portion 2020 and a half body bottom portion 2010, each having a number of hinge-like projections 2005 molded or machined into the input and output ends. As shown here, there are four hinged body portions 2040 containing an integral barb holder designed to receive four barbs 2060 each and a semi-cylindrical barb keeper 2045 attached to each hinged body portion 2040 to securely lock the barbs 2060 into place.

With reference now to Figure 31, an assembled hinged, ruggedized cylindrical shuffle module 2000 is shown with the hinged portions 2040 opened at both the input and output ends of the module 2000. The hinged body portions 2040 have been hooked in place to the hinges 2005 of the upper and lower half body portions of the module 2000 and the input and output ends of the manifold 2050 are exposed.

A suggested assembly technique for this type of module 2000 may be described as follows. A cable jumper is made up to twice the desired length, it is tested and then cut in half. The heat shrink and crimp tube is placed on each jumper half following the removal of an appropriate amount of ruggedized jacket, the jacket end is split to accommodate the diameter of the crimp barb 2060. The attachment barb is then crimped onto the end of the

jacket and these four steps are repeated until enough jacket jumper halves have been created for both the input and output ends of the optical circuit to be created. Again, the operator should produce 8 jumper halves of the desired length. The operator then sequences the eight input jumper halves and directs the individual optical fibers to the appropriate openings of the manifold in a manner similar to that which was described for Figures 27 and 28. The operator then gathers the fibers and completes the eight output jumper halves. Upon completion of the fiber routing, the operator may then close the hinged portion 2040 at both the input and output end of the module 2000 and further secure the ruggedized cables using an end ring, not shown. Of course, although this particular embodiment is intended for use with ruggedized fiber optic cables it may also be used with loose collections of individual optical fibers which may later be ribbonized or connectorized, if desired.

With reference now to Figures 32 and 33, a further embodiment of an in-line shuffle module 2100 is shown. This particular embodiment features a generally rectangular body portion and appropriate fittings 2130 for ruggedized cable attachment at one end and an opening 2140 for loose or ribbonized optical fibers at the output end. As best seen in Figure 33, this module features generally rectangular base 2110 and lid 2120 portions which may be molded or machined to fit about the compact shuffle manifold 2150. The base portion 2110 is further provided with a number of barb keepers which are positioned in a side-by-side manner at one end of the module 2100. The ruggedized cables may be crimped and attached to the barbs 2160 and fitted into the barb keeper as described previously in regard to the other in-line modules. The fibers are then directed to the appropriate input openings of the shuffle manifold 2150 and then exit at the output end of the manifold where they may again be collected up and ribbonized, if desired. This substantially rectangular box-like design is particularly well suited for mounting to lie flat on a card which may subsequently be placed into a rack type system. As with the cylindrical modules, this box-type module also provides a high degree of physical protection to the fibers prior to entering the shuffle and to the shuffle module itself, both from mechanical hazards and those presented by heat or flame.

Although preferred embodiments of the invention have been described in the examples and foregoing description, it will be understood that the invention is not limited to the embodiments disclosed, but is capable of numerous rearrangements and

modifications of the parts and elements without departing from the spirit of the invention, as defined in the following claims. Therefore, the spirit and the scope of the appended claims should not be limited to the description of the preferred embodiments contained herein.

5

## WHAT IS CLAIMED IS:

1. A three dimensional optical circuit comprising:  
a plurality of optical fibers;  
5 an optical manifold comprising:  
a unitary body having an input end and an output end;  
said input end having a plurality of input openings in a first ordered  
arrangement;  
said output end having a plurality of output openings in a second ordered  
10 arrangement which differs from that of said first ordered arrangement;  
said unitary body further comprising a plurality of integrally formed  
passageways, each of said passageways connecting a single input opening with a  
single output opening; and  
wherein each of said plurality of optical fibers is disposed within one of said  
15 passageways of the optical manifold.
2. The three dimensional optical circuit of claim 1, wherein the unitary body is  
formed of a polymeric material.
- 20 3. The three dimensional optical circuit of claim 1, wherein the unitary body is  
formed by an additive manufacturing process.
4. The three dimensional optical circuit of claim 1, wherein the optical fibers slide  
freely within the passageways of the optical manifold.
- 25 5. The three dimensional optical circuit of claim 1, wherein the optical fibers are  
fixed in place within the passageways of the optical manifold.
6. The three dimensional optical circuit of claim 5, wherein the passageways of the  
30 optical manifold have been filled with an adhesive resin.

7. The three dimensional optical circuit of claim 6, wherein the optical manifold is formed of a material which is significantly more soluble than the adhesive resin.

5 8. The three dimensional optical circuit of claim 5, wherein the passageways of the optical manifold contain at least one lateral opening disposed between the input end and the output end of the manifold.

9. The three dimensional optical circuit of claim 1, wherein the optical manifold has been enclosed within a protective housing.

10

10. The three dimensional optical circuit of claim 10, wherein at least one optical connector is anchored to the protective housing.

11. The three dimensional optical circuit of claim 1, wherein the optical manifold has been mounted to a plug-in card to form an optical shuffle module.

15

12. A three dimensional optical module comprising:  
a housing;  
at least one ruggedized cable attachment disposed on the exterior of said housing;  
at least one bulkhead connector disposed on the exterior of said housing;  
an optical manifold disposed within said housing, said optical manifold comprising:

20

a unitary body having an input end and an output end;

said input end having a plurality of input openings in a first ordered arrangement;

25

said output end having a plurality of output openings in a second ordered arrangement which differs from that of said first ordered arrangement;

said unitary body further comprising a plurality of integrally formed passageways, each of said passageways connecting a single input opening with a single output opening; and

30

a plurality of optical fibers, said plurality of optical fibers entering the housing via the at least one ruggedized cable attachment, passing through the optical manifold, and terminating at the at least one bulkhead connector.

- 5      13.      The three dimensional optical circuit of claim 12, wherein the at least one bulkhead connector further comprises a plurality of ferrule spring, push-pin connectors.
14.      The three dimensional optical module of claim 12, wherein the at least one ruggedized cable attachment and the at least one bulkhead connector are disposed on a  
10      single surface of the exterior of the housing.
15.      The three dimensional optical module of claim 12, wherein the housing further comprises holes to facilitate rack mounting.
- 15      16.      A method of making a three dimensional optical circuit comprising the steps of:  
forming an optical manifold comprising:  
a body having an input end and an output end;  
said input end having a plurality of input openings in a first ordered  
arrangement;  
20      said output end having a plurality of output openings in a second ordered  
arrangement which differs from that of said first ordered arrangement;  
said body comprising a plurality of integrally formed passageways, each of  
said passageways connecting a single input opening with a single output opening;  
providing a plurality of optical fibers; and  
25      inserting each of said plurality of optical fibers into the input openings of the  
optical manifold such that each is disposed within the optical manifold on a one-fiber-per-  
passageway basis.
17.      The method of claim 16, wherein the step of forming an optical manifold further  
30      comprises using a rapid prototyping technique.

18. The method of claim 17, wherein the rapid prototyping technique is stereolithography (SLA).

19. The method of claim 16, wherein the step of forming an optical manifold further  
5 comprises stacking a plurality of grooved plates.

20. The method of claim 19, wherein the plurality of grooved plates are formed by milling a plurality of solid plates.

10 21. The method of claim 19, wherein the plurality of grooved plates are formed using a rapid prototyping technique.

22. The method of claim 16, further comprising the step of disposing the optical manifold within a protective housing.

15 23. The method of claim 22, wherein the protective housing is suitable for rack mounting within an electronic enclosure.

20 24. A method of making a three dimensional optical circuit comprising the steps of:  
forming an optical manifold comprising:  
a body having an input end and an output end;  
said input end having a plurality of input openings in a first ordered arrangement;  
said output end having a plurality of output openings in a second ordered  
25 arrangement which differs from that of said first ordered arrangement;  
said body comprising a plurality of integrally formed passageways, each of said passageways connecting a single input opening with a single output opening;  
said body further comprising at least one ruggedized cable attachment;  
providing at least one ruggedized optical cable having a plurality of optical fibers  
30 enclosed within a protective exterior jacket;  
cutting back a portion of the protective exterior jacket of the at least one ruggedized optical cable;

passing the exposed plurality of optical fibers through a strain relief boot, a crimp ring and a crimp barb;

crimping the crimp ring to the remaining exterior jacket of the at least one ruggedized optical cable;

5 fitting the crimp ring within the crimp barb;

connecting the crimp barb to the at least one ruggedized cable attachment of the optical manifold; and

10 inserting each of said plurality of optical fibers into the input openings of the optical manifold such that each is disposed within the optical manifold on a one-fiber-per-passageway basis.

25. The method of claim 24, further comprising the step of spreading the plurality optical fibers apart with a pitch tool prior to the step of inserting the plurality of optical fibers into the input openings.

15

26. The method of claim 24, further comprising the step of collecting the plurality of optical fibers at the output openings of the manifold and ribbonizing them.

20

27. The method of claim 26, further comprising the step of enclosing the ribbonized optical fibers within a protective exterior jacket.

28. An in-line optical shuffle module comprising:

a housing;

25 an optical manifold disposed within said housing, said optical manifold comprising:

a body having an input end and an output end;

said input end having a plurality of input openings in a first ordered arrangement;

30 said output end having a plurality of output openings in a second ordered arrangement which differs from that of said first ordered arrangement; and

said body further comprising a plurality of integrally formed passageways, each of said passageways connecting a single input opening with a single output opening.

5      29.    The in-line optical shuffle module of claim 28, wherein said housing further comprises a substantially cylindrical tubular body with endcaps.

30.    The in-line optical shuffle module of claim 29, wherein said tubular body is formed of a metal.

10

31.    The in-line optical shuffle module of claim 29, wherein said tubular body is formed of a flame resistant polymer.

15

32.    The in-line optical shuffle module of claim 28, wherein said housing further comprises at least one semi-cylindrical bottom portion and at least one semi-cylindrical top portion.

20

33.    The in-line optical shuffle module of claim 28, wherein said housing further comprises at least one semi-cylindrical bottom portion, at least one semi-cylindrical top portion and a shuffle cradle.

34.    The in-line optical shuffle module of claim 28, wherein said optical manifold is a unitary part formed using a rapid prototyping technique.

25

35.    The in-line optical shuffle module of claim 34, wherein said optical manifold is formed using stereolithography.

30

36.    The in-line optical shuffle module of claim 28, wherein said housing further comprises at least one hinged body portion that may pivot about an axis to provide access to the optical manifold.

37. The in-line optical shuffle module of claim 36, wherein said housing further comprises a substantially cylindrical body portion having pins proximate the input and output ends of the optical manifold and having a plurality of hinged body portions pivotally mounted to said pins.

5

38. The in-line optical shuffle module of claim 28, wherein said housing further comprises a substantially rectangular box-like body.

10

39. The in-line optical shuffle module of claim 38, wherein said housing further comprises a plurality of fittings for ruggedized cable attachment at one end.

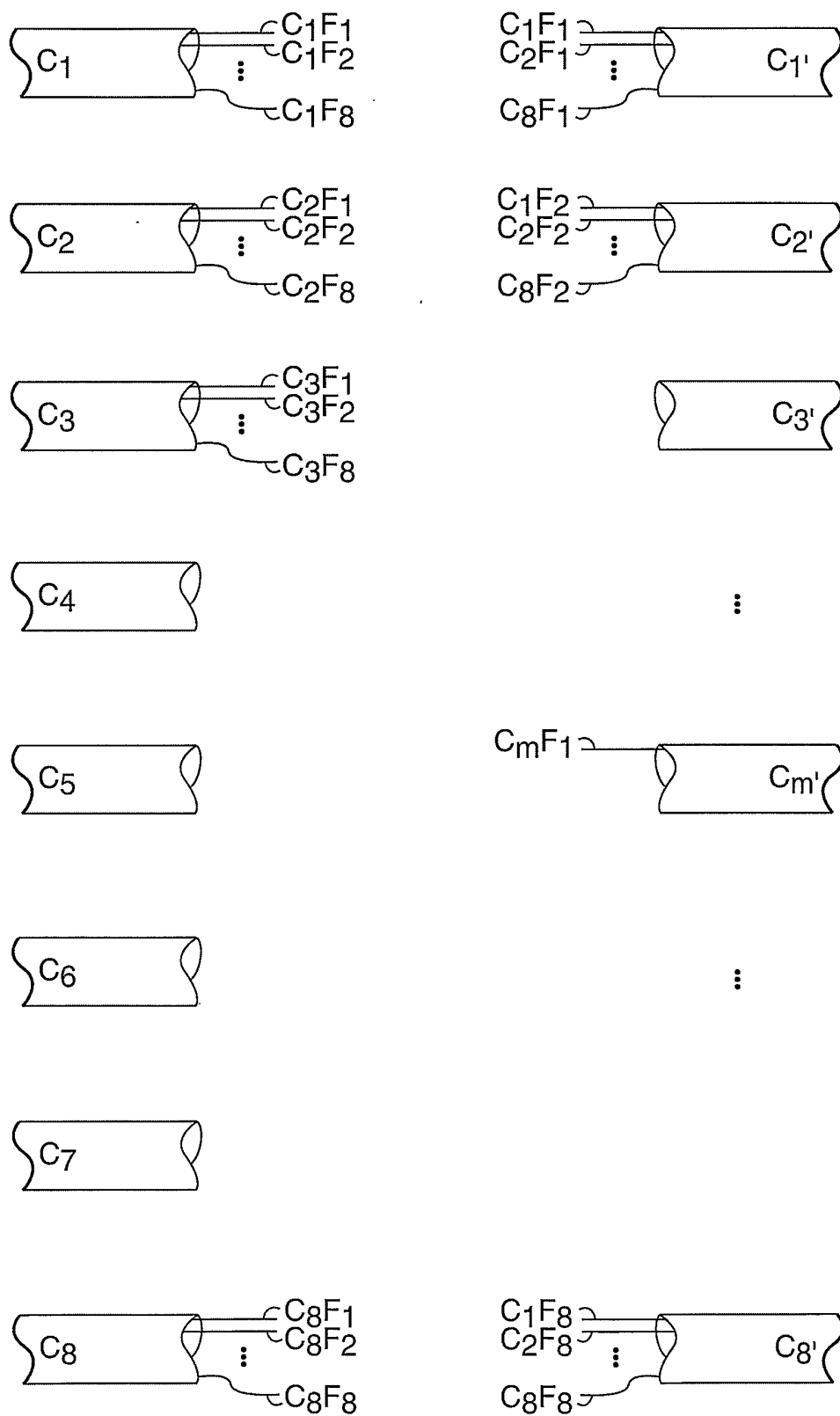
40. The in-line optical shuffle module of claim 39, wherein said plurality of fittings comprise a plurality of barb keepers positioned in a side-by-side manner.

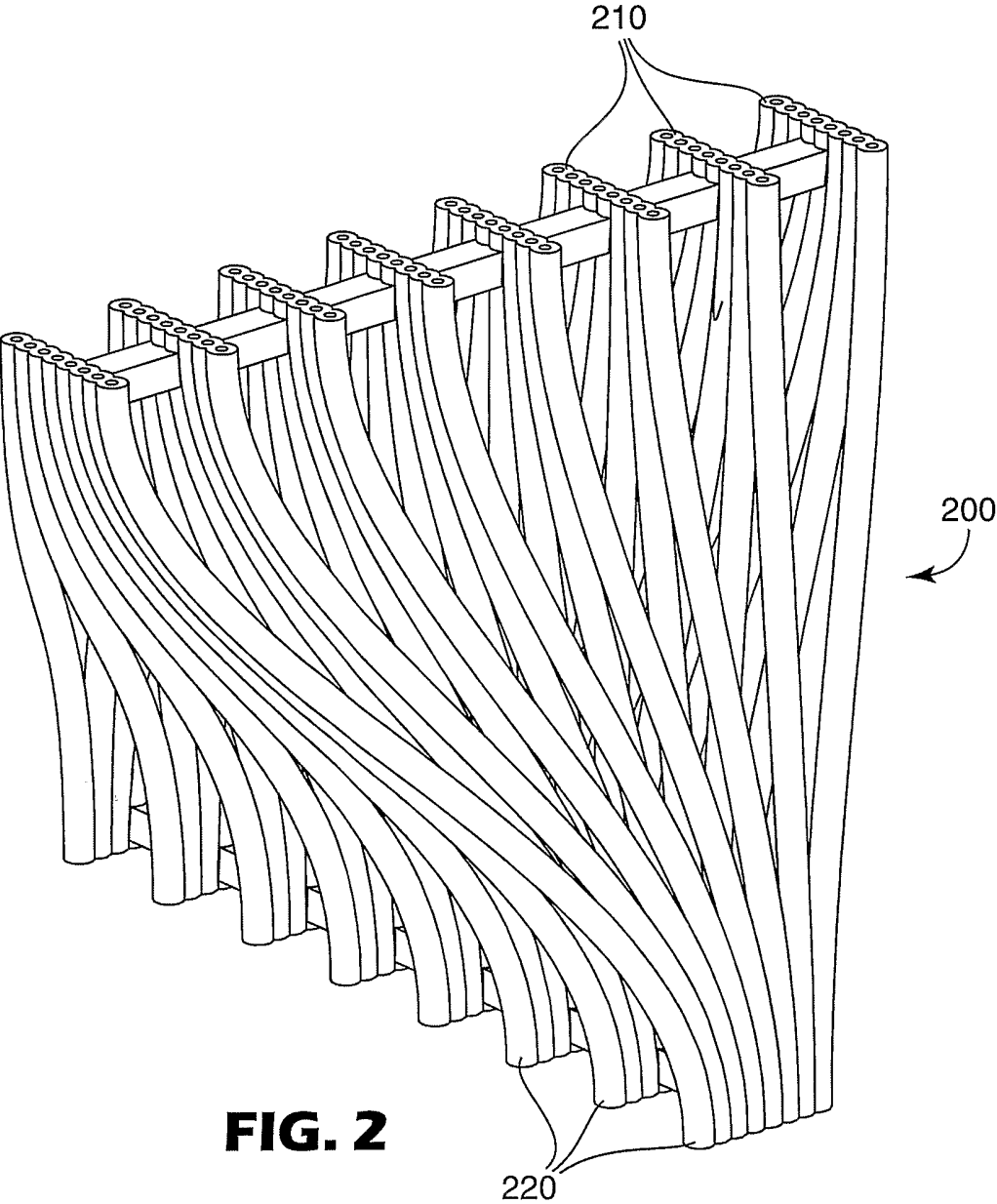
15

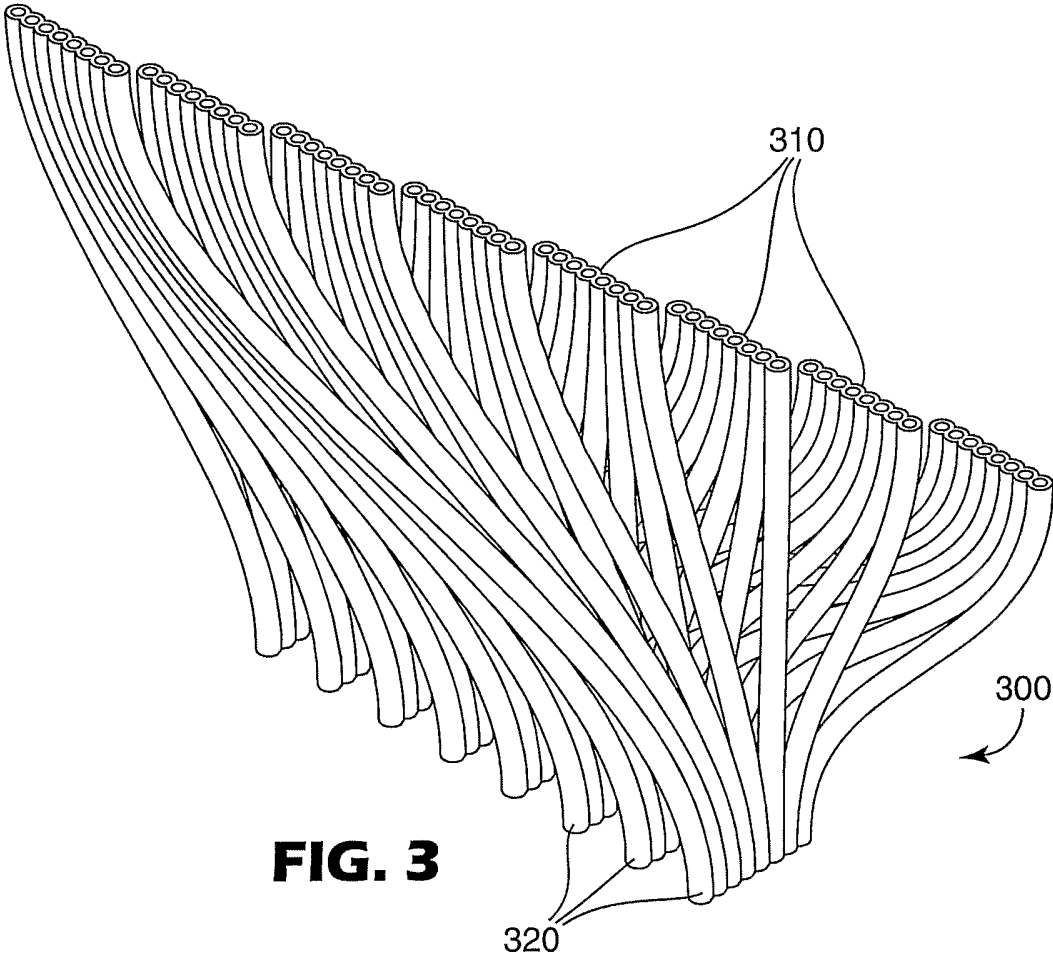
41. A three dimensional optical circuit comprising the in-line shuffle module of claim 1 and a plurality of optical fibers, wherein each of said plurality of optical fibers is disposed within the passageways of the optical manifold on a one-fiber-per-passageway basis.

20

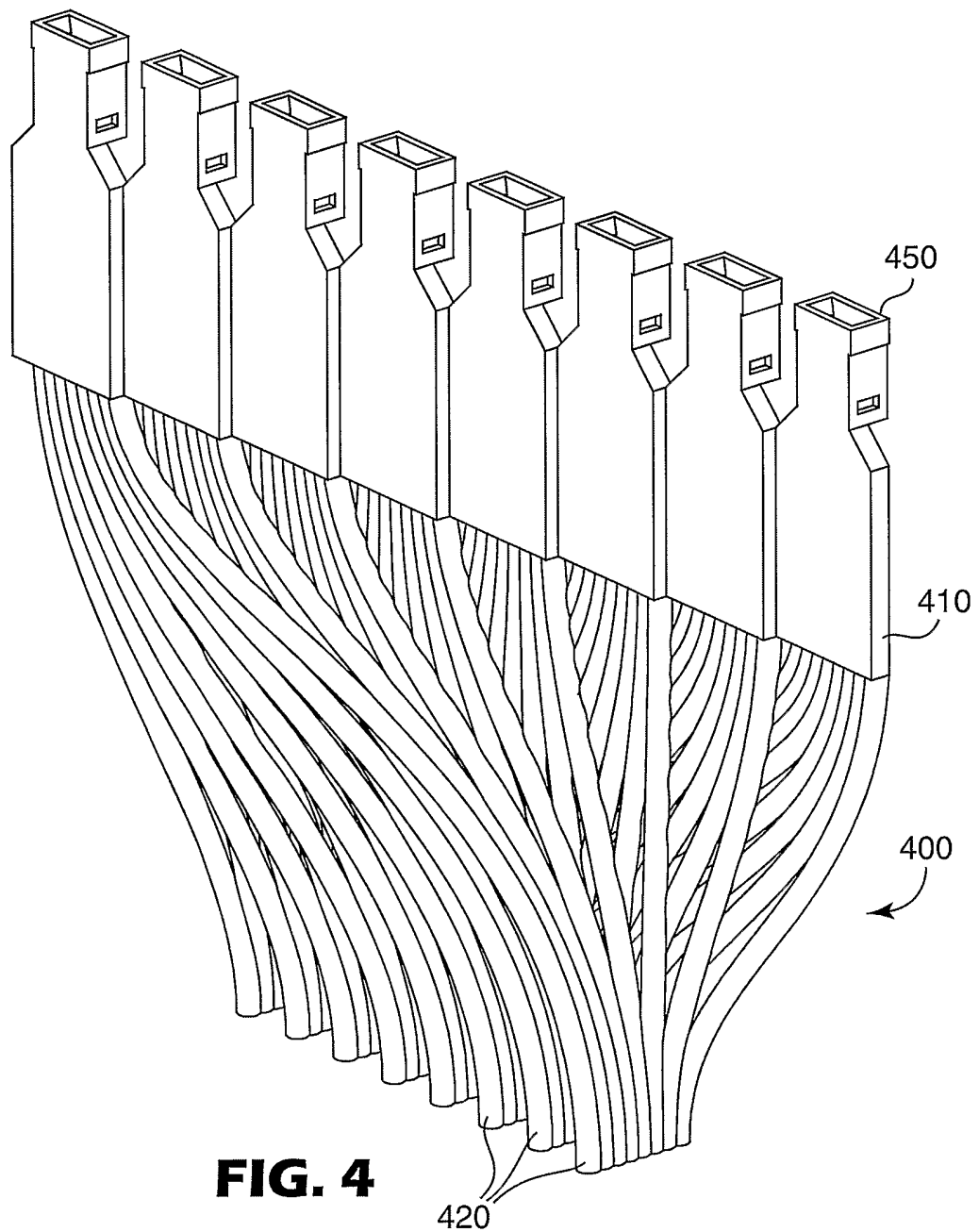
1/29

**FIG. 1**

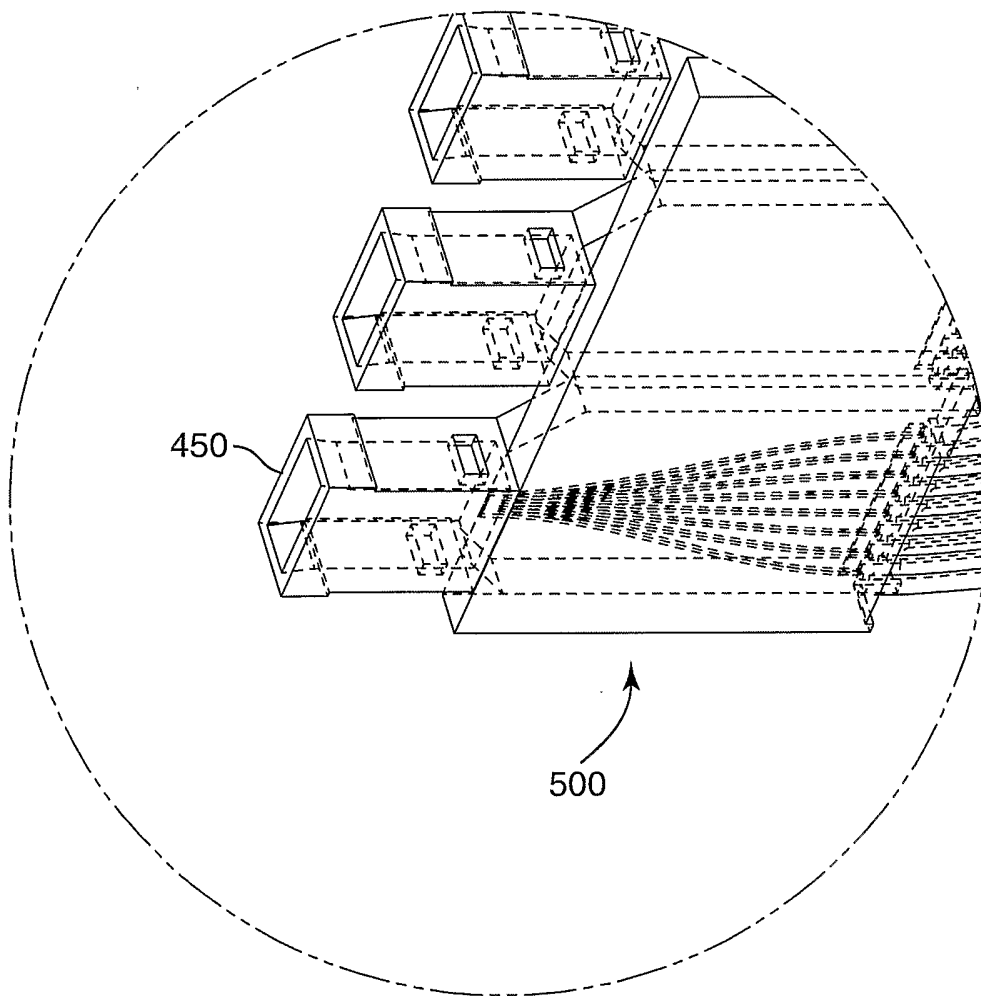




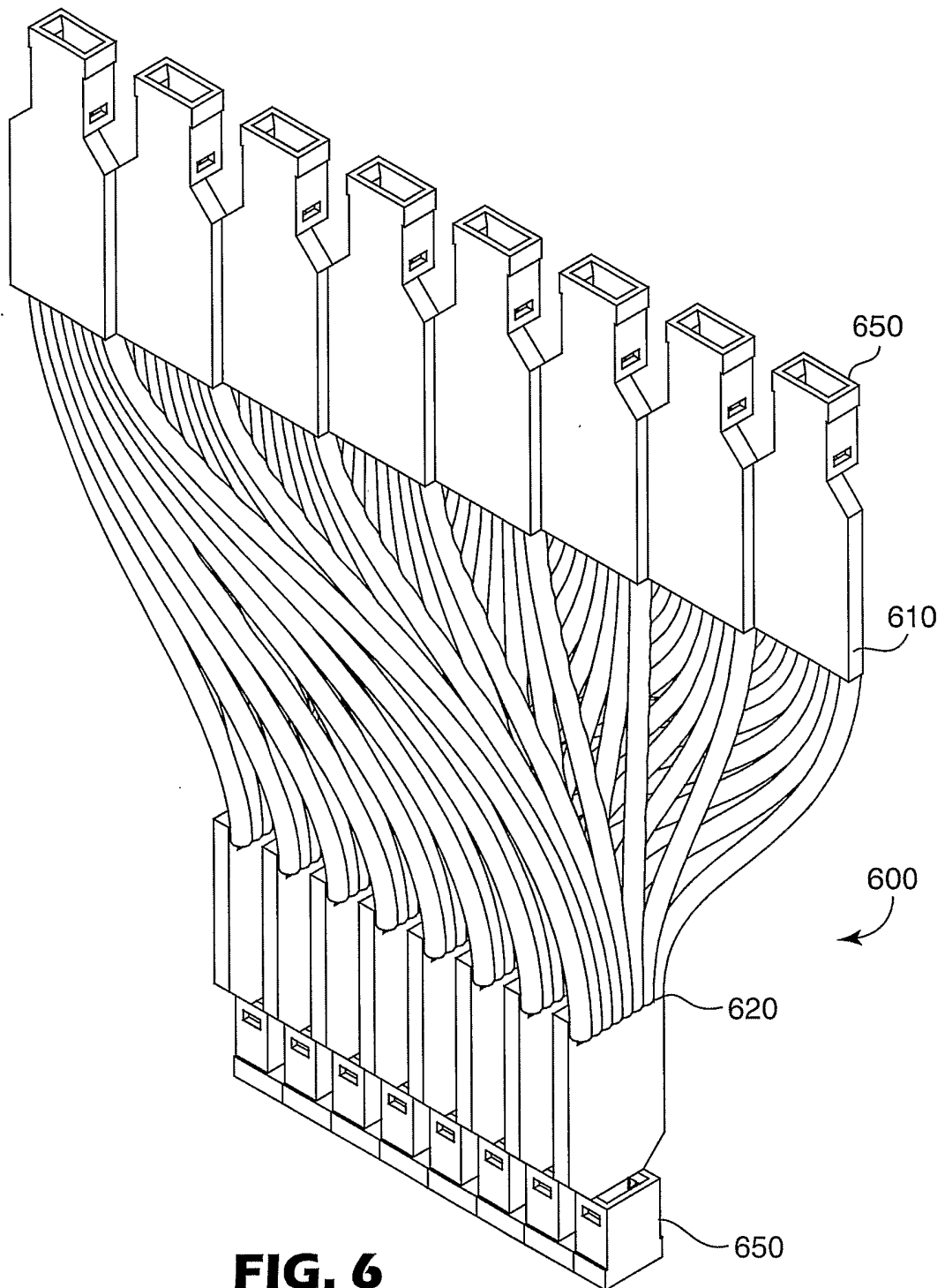
4/29



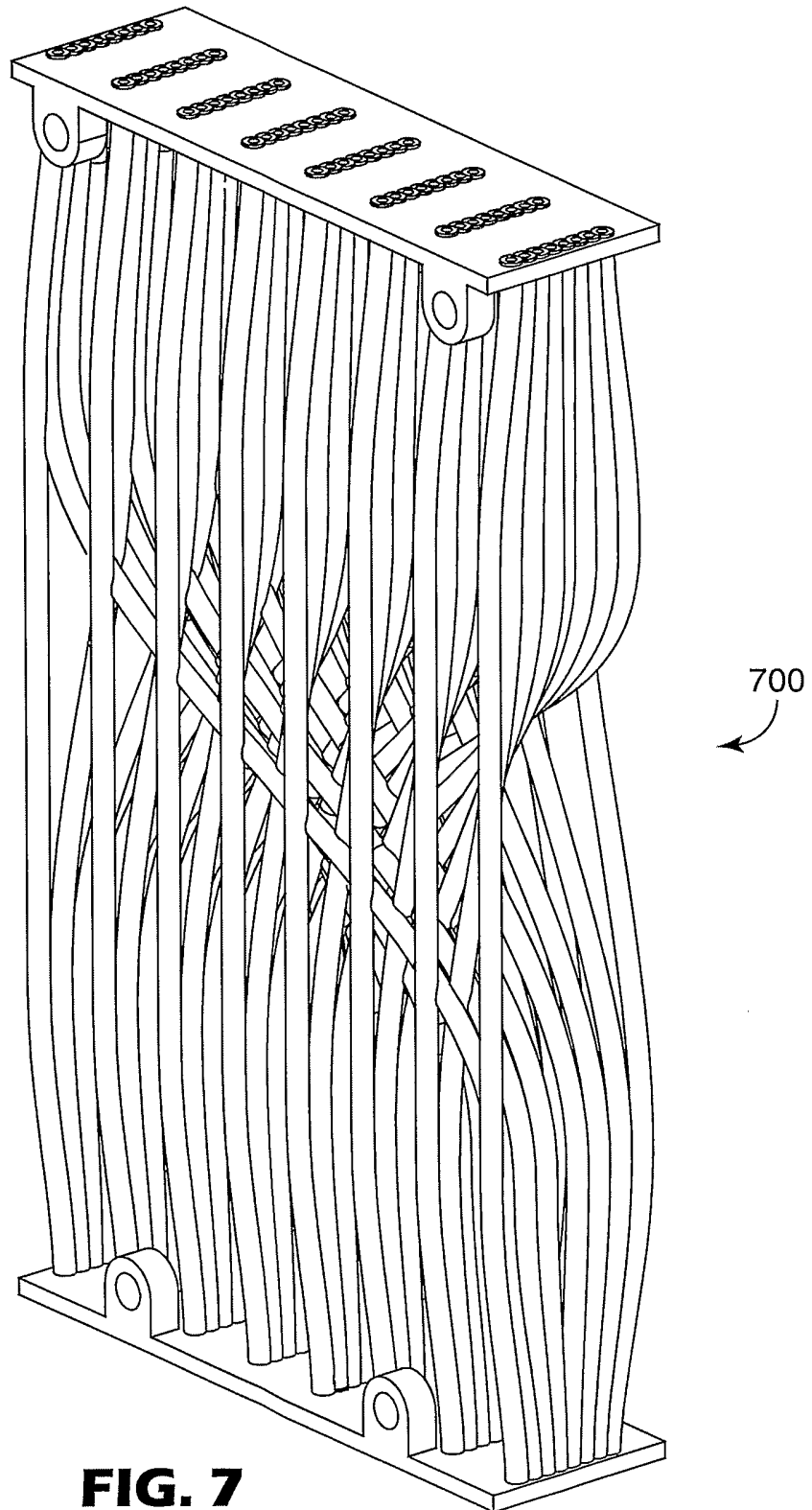
5/29

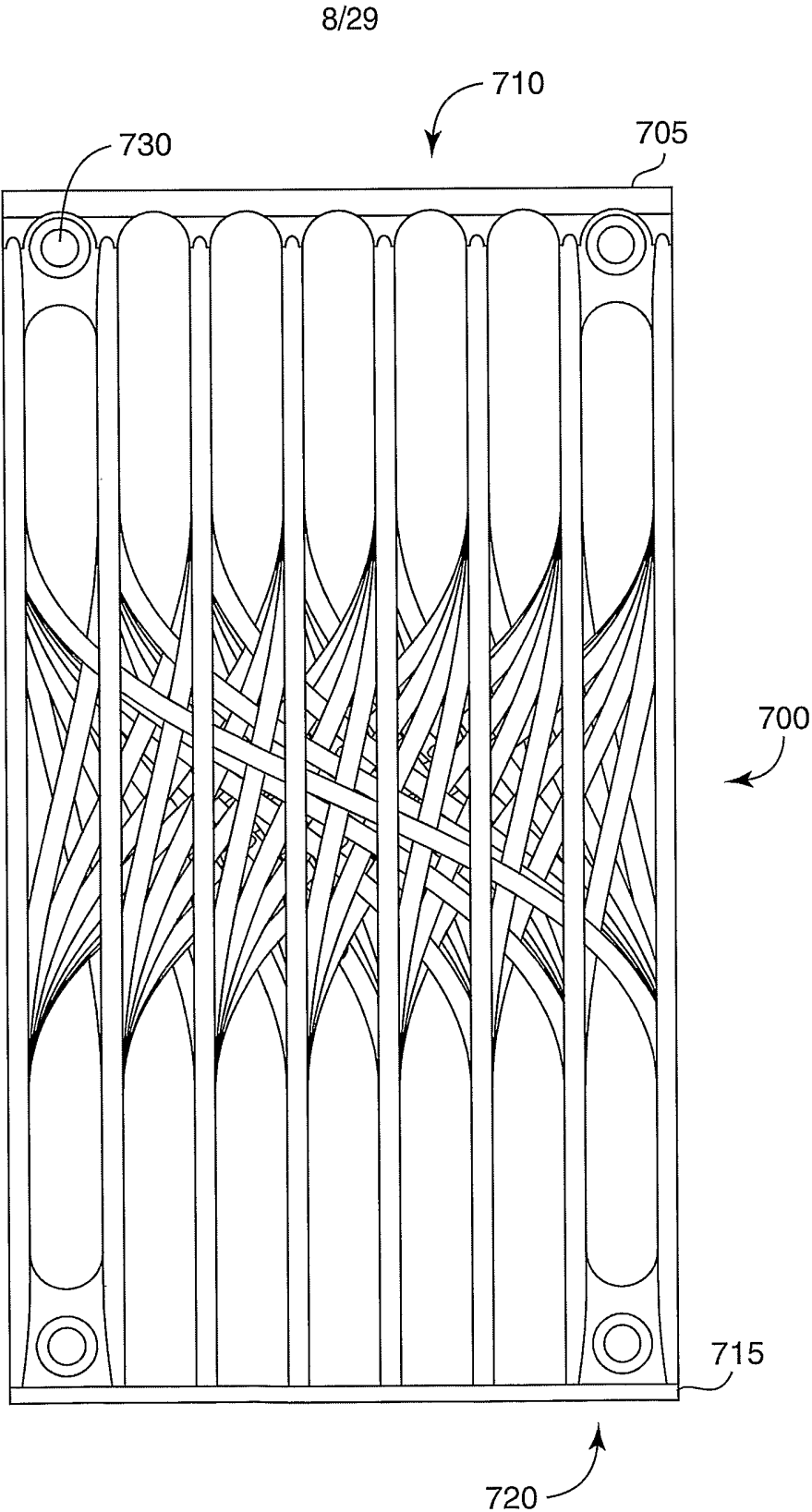
**FIG. 5**

6/29

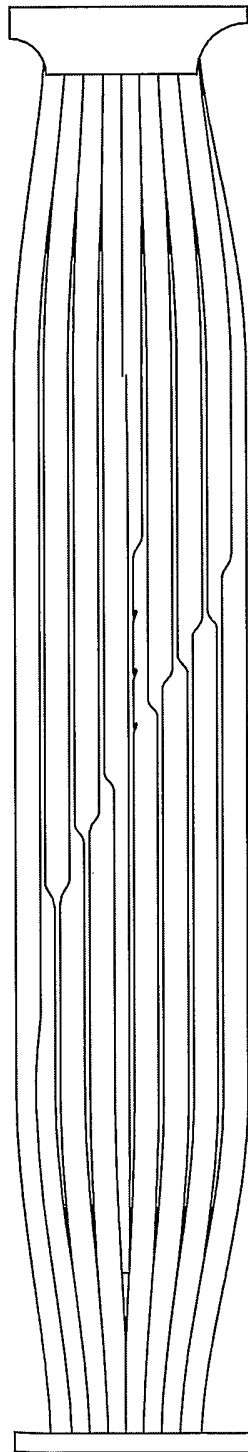
**FIG. 6**

7/29





9/29



700

**FIG. 9**

10/29

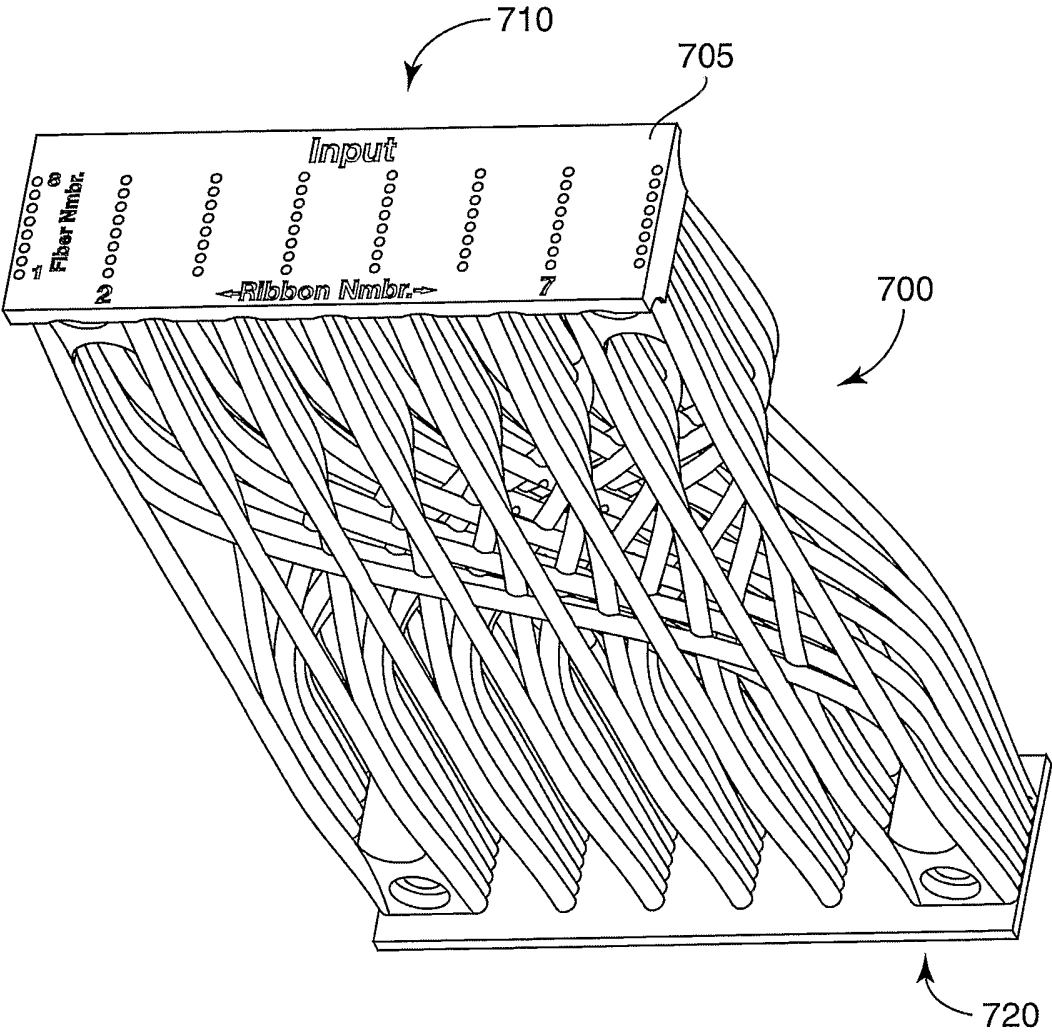


FIG. 10

11/29

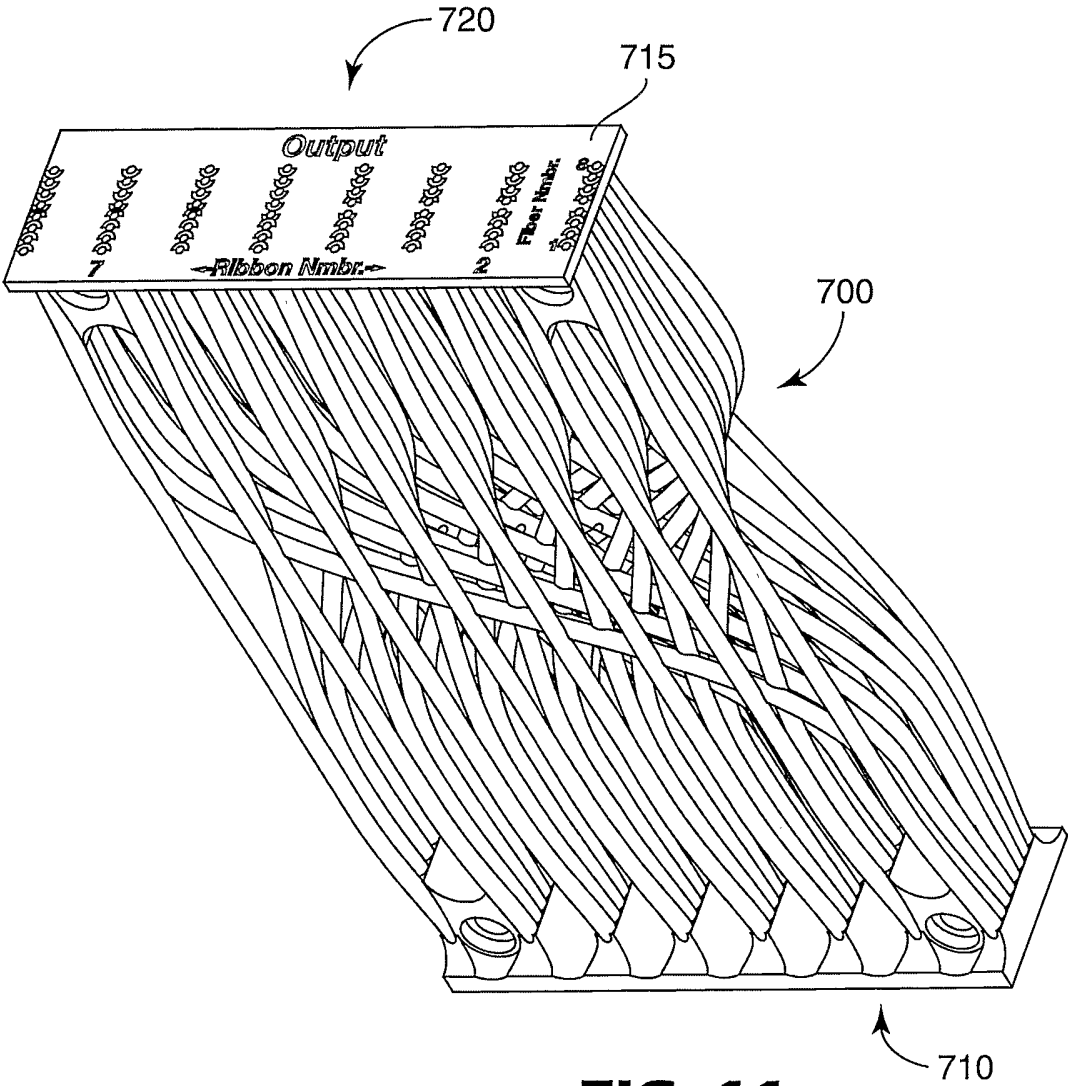


**FIG. 11**

12/29

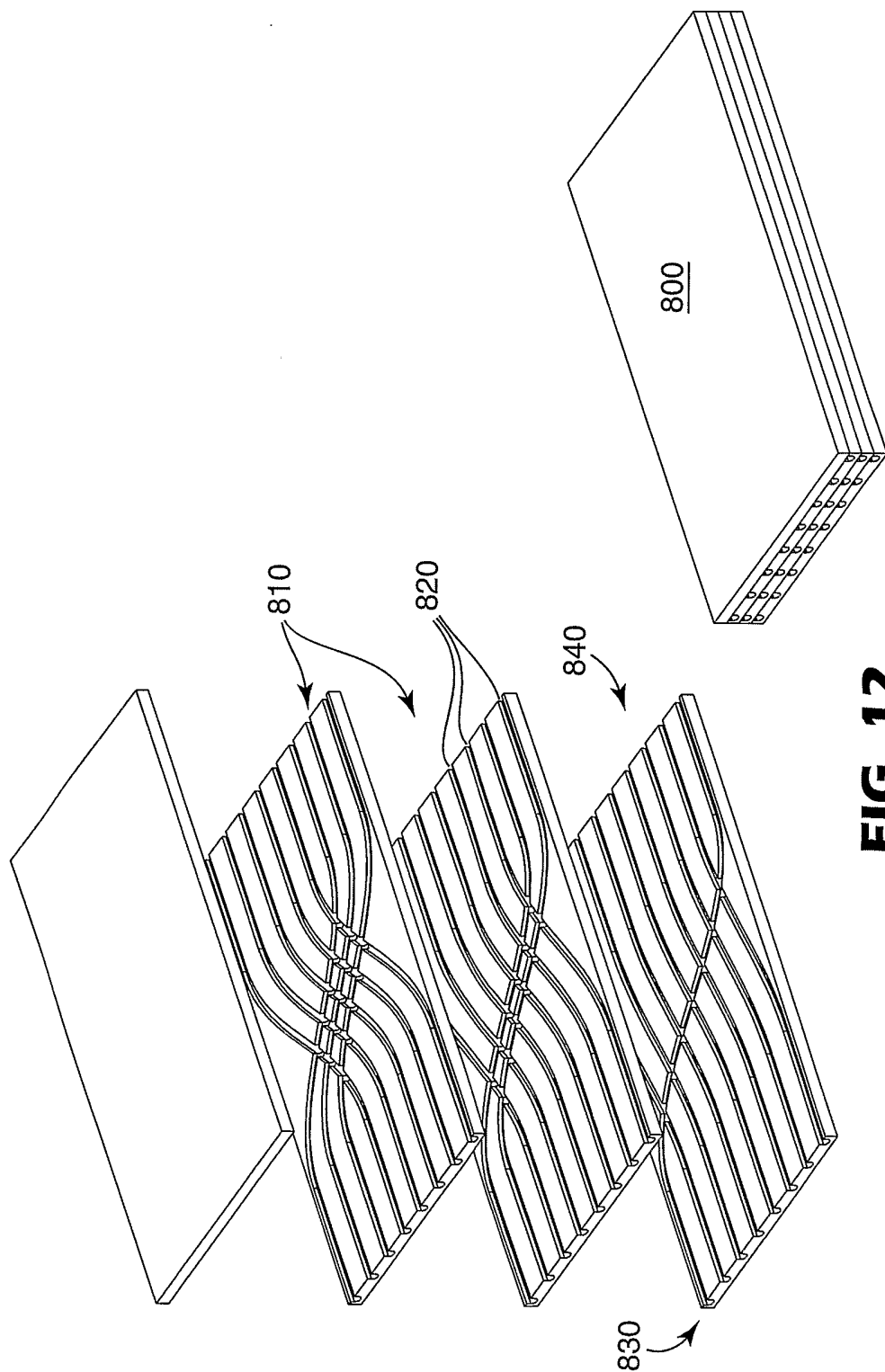


**FIG. 12**

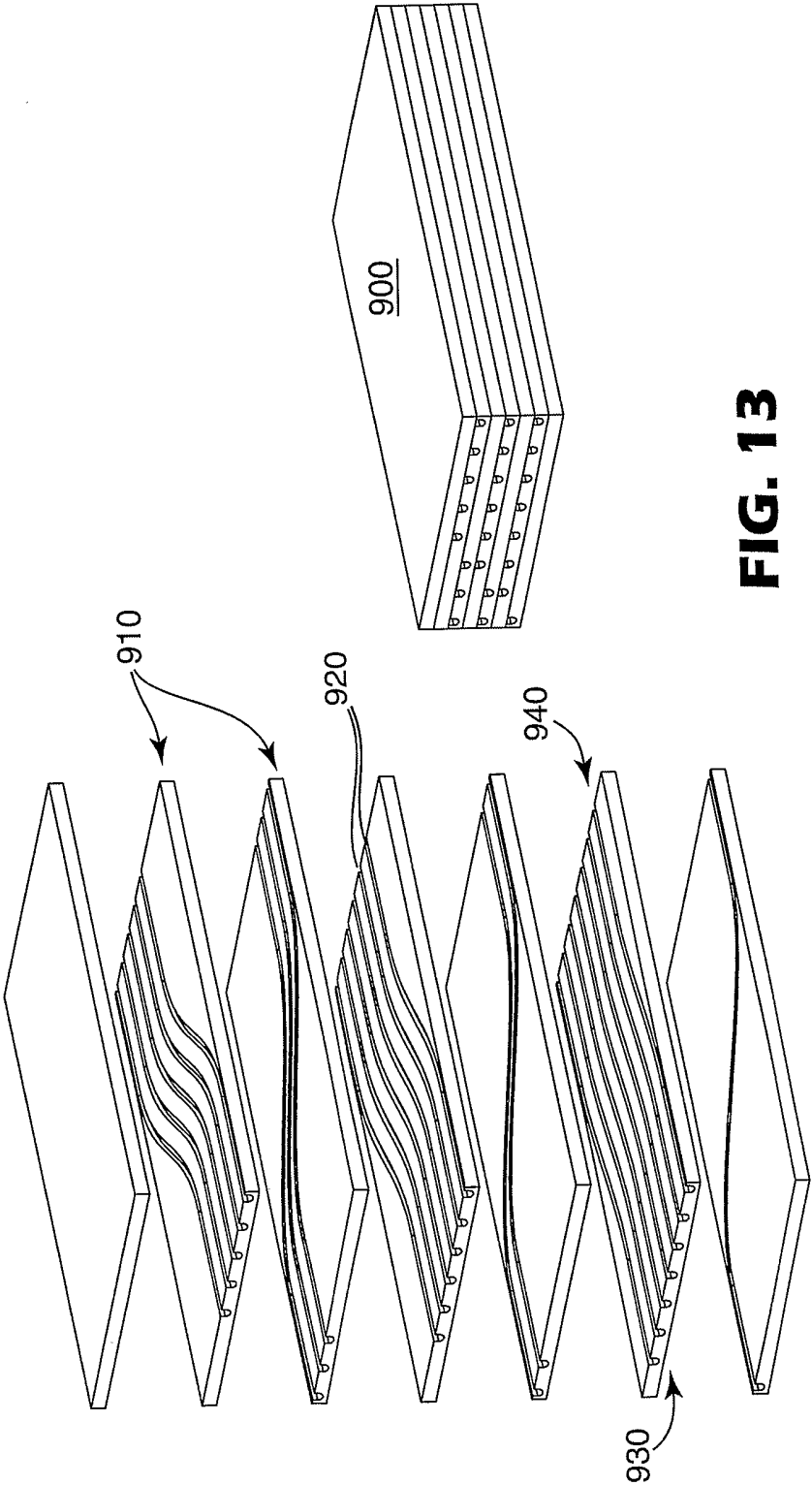


FIG. 13

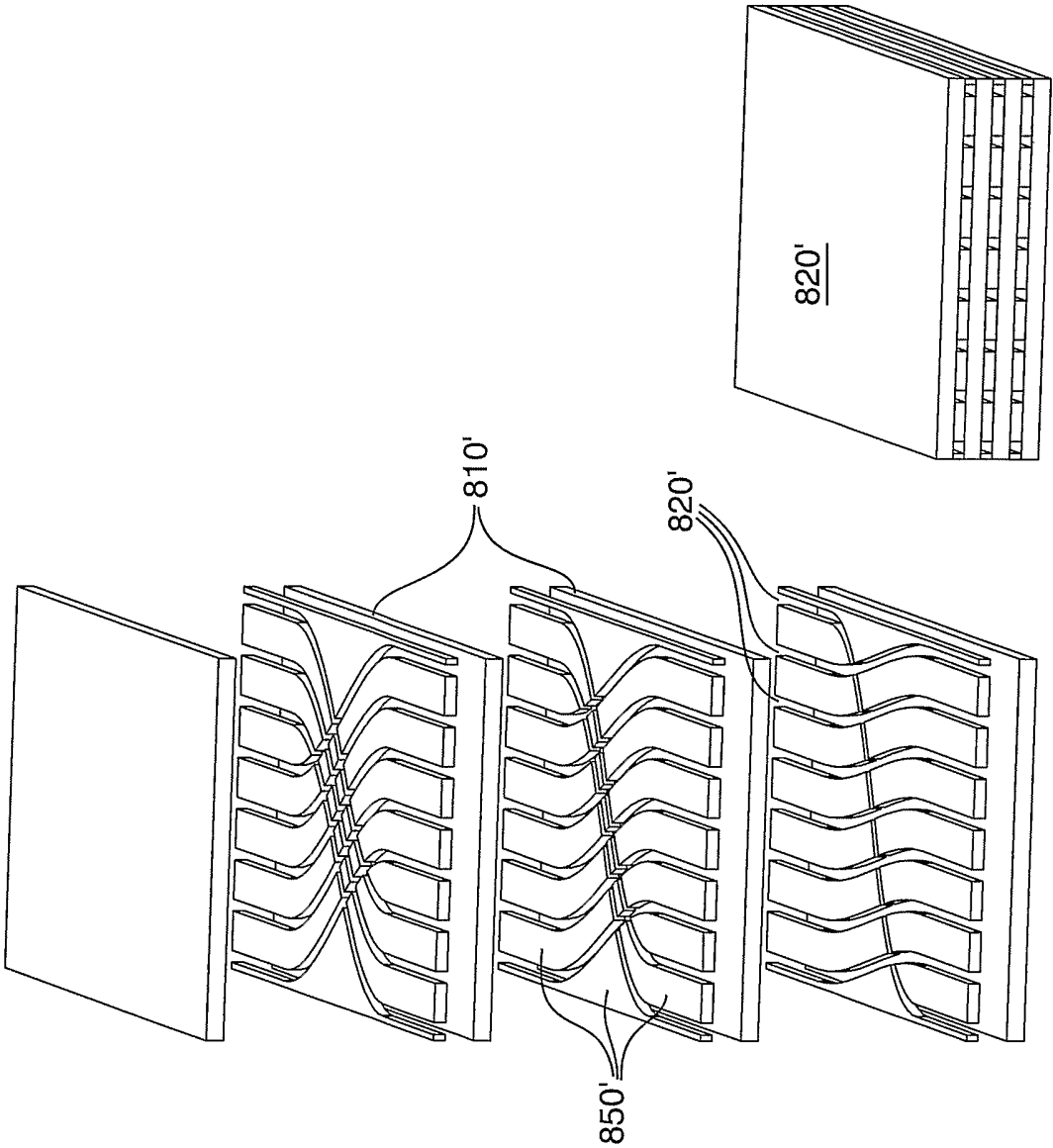


**FIG. 14**

15/29

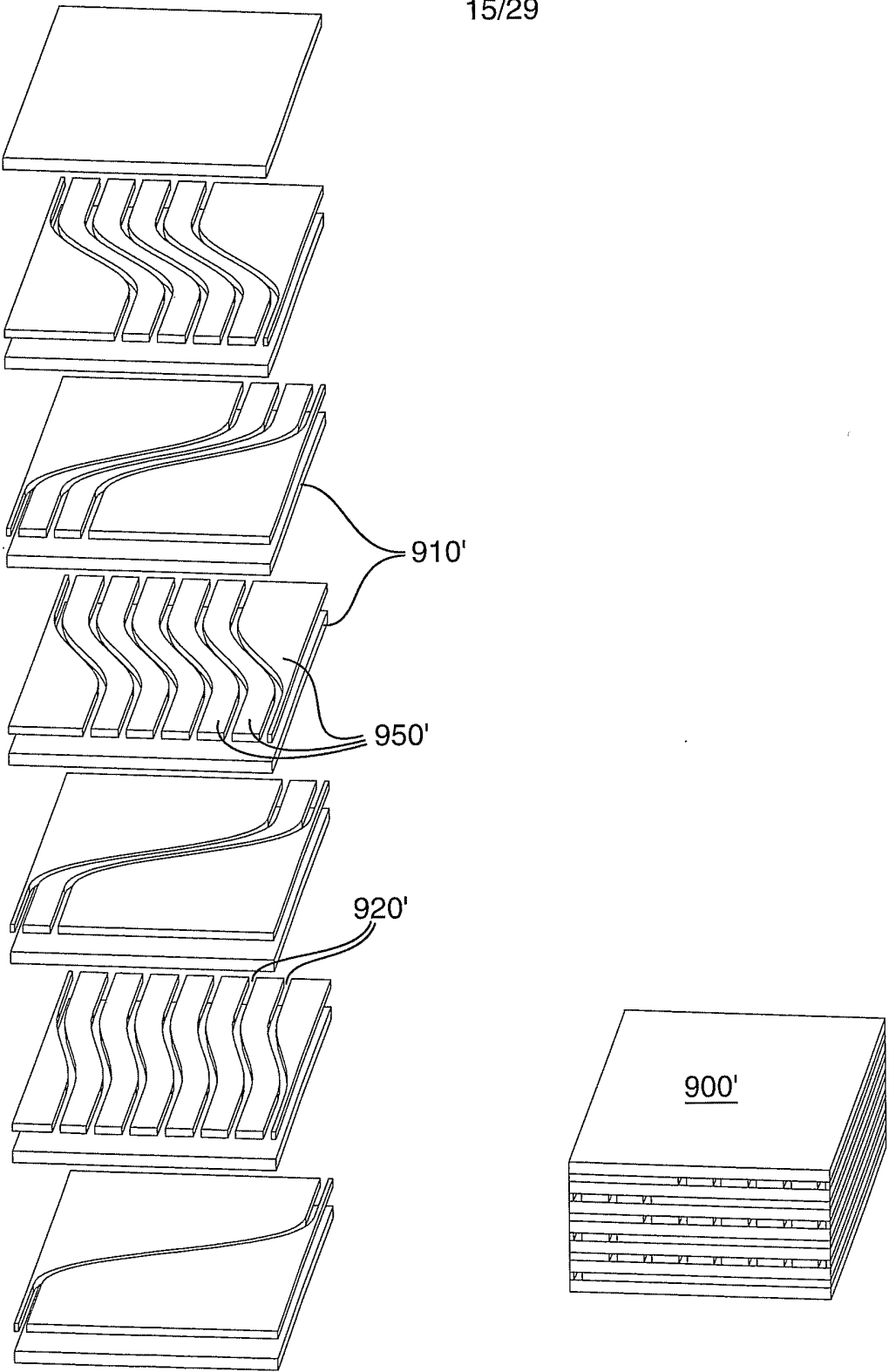


FIG. 15

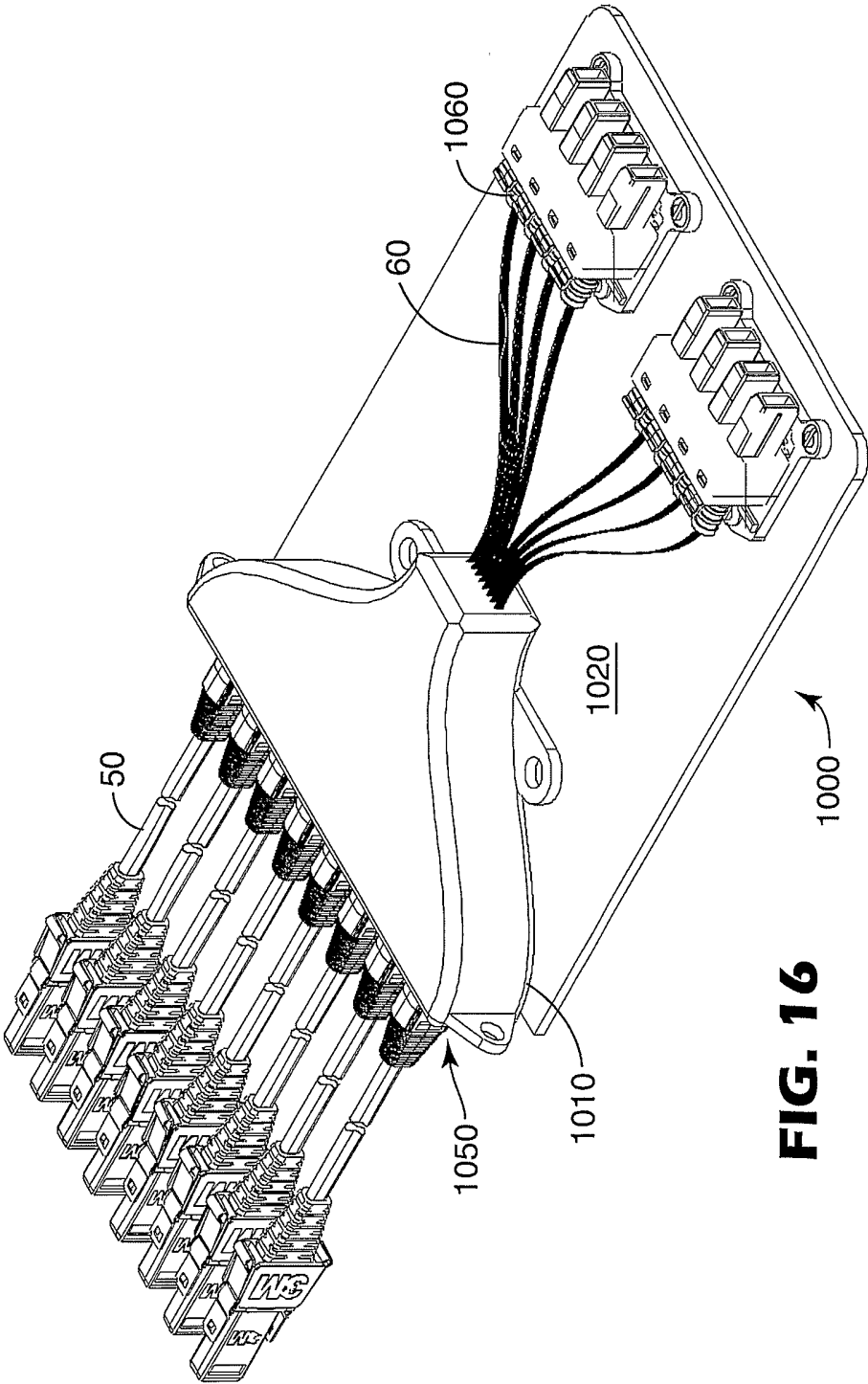


**FIG. 16**

17/29

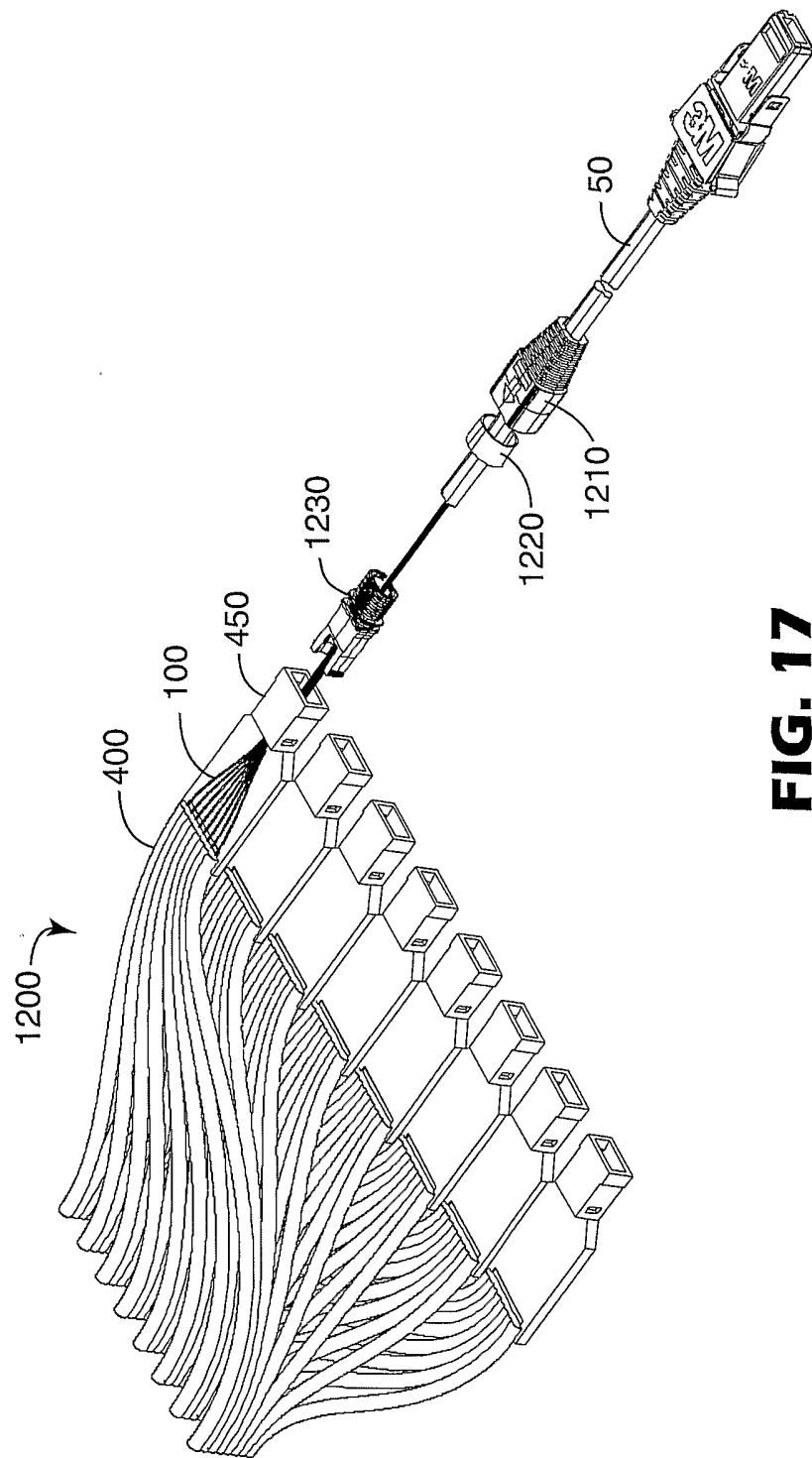


**FIG. 17**

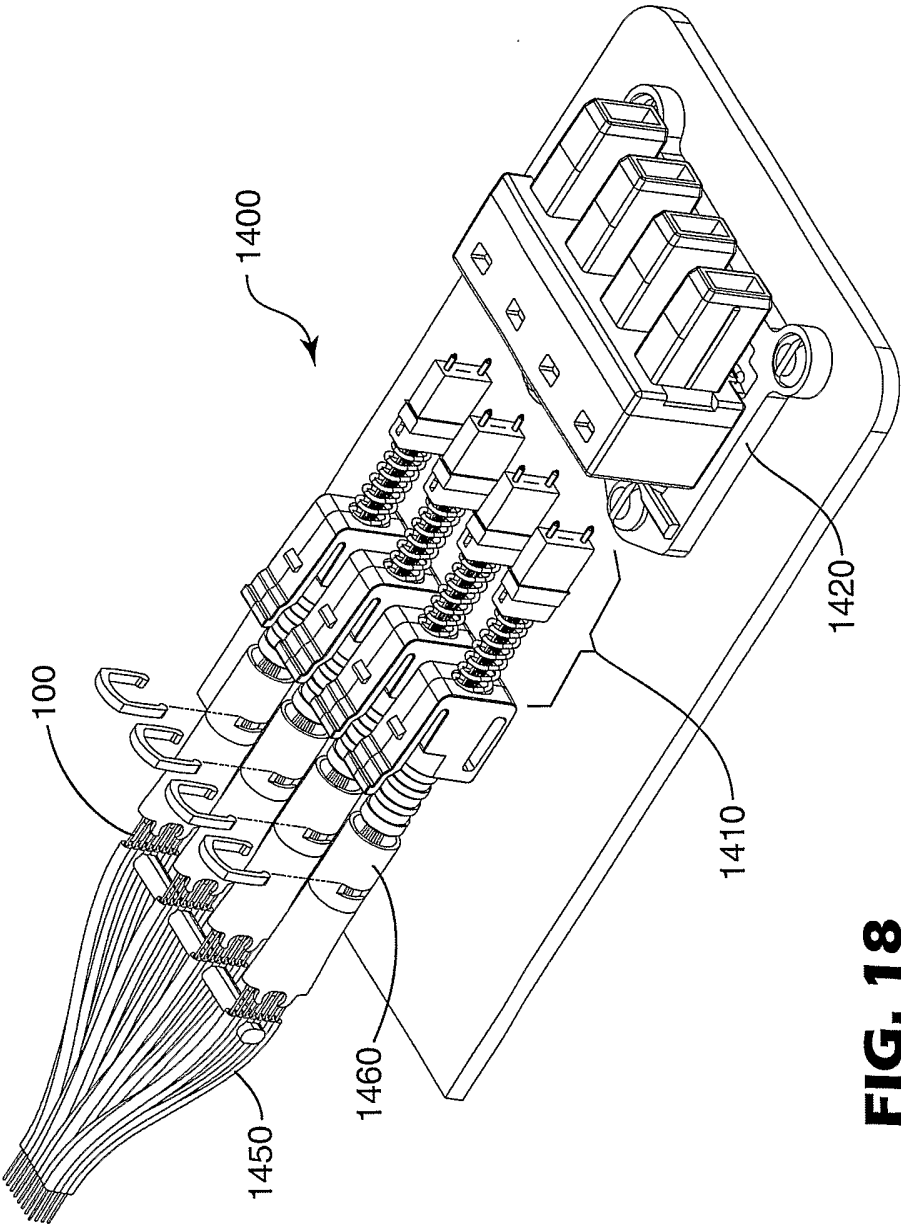


**FIG. 18**

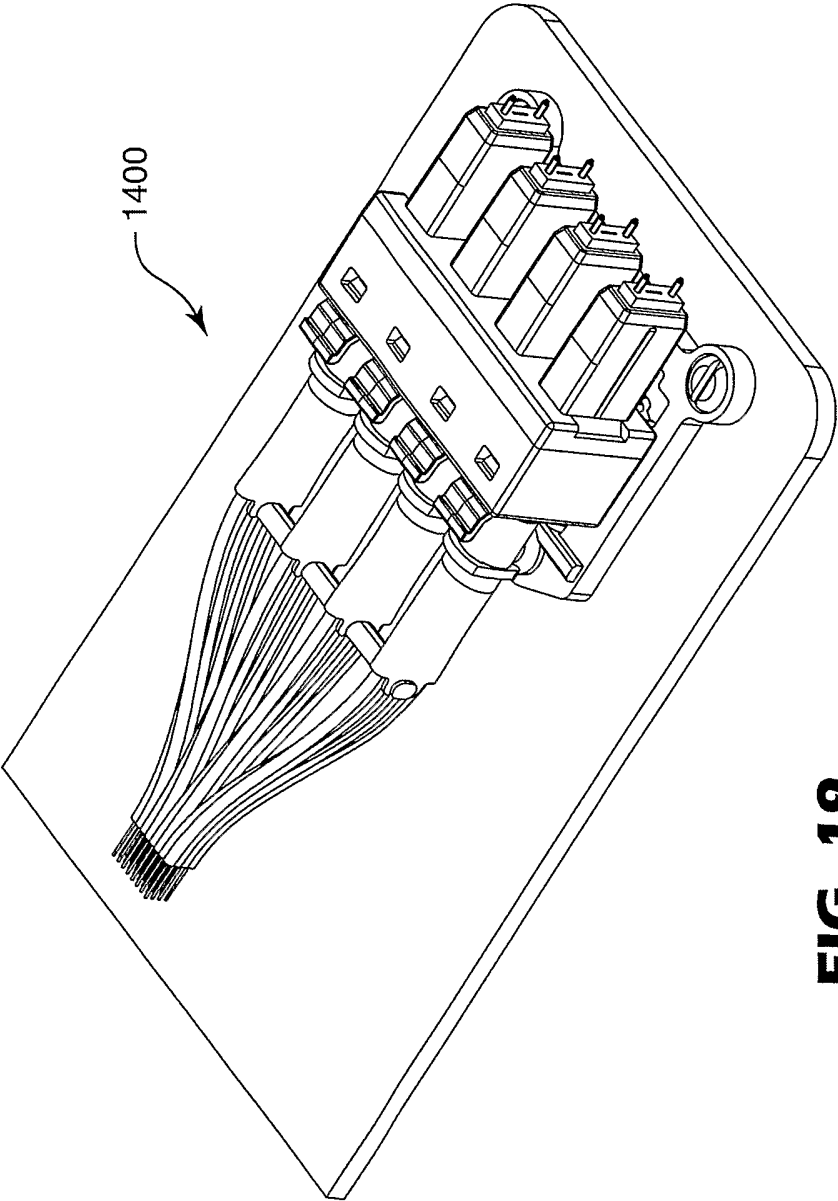


**FIG. 19**

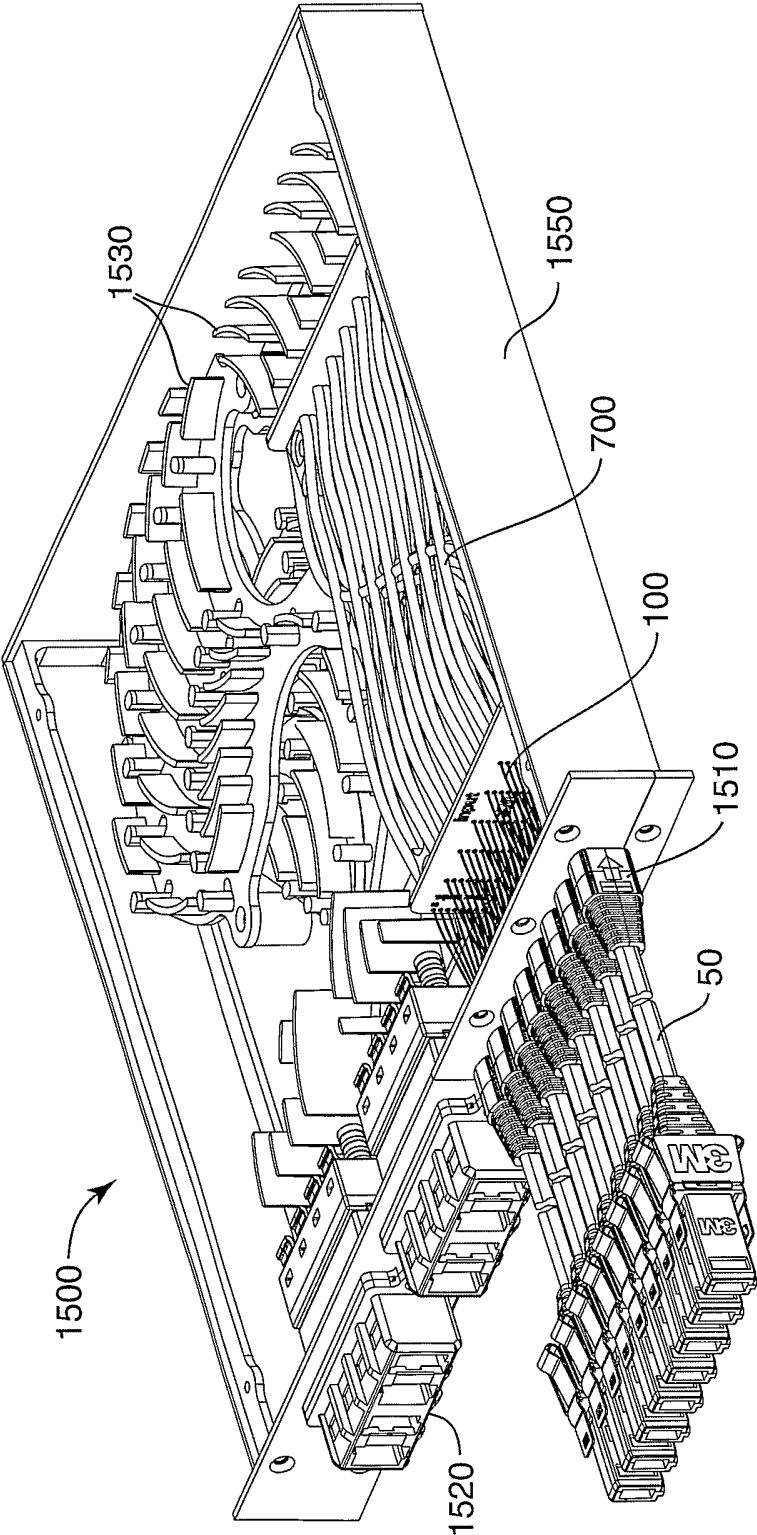


**FIG. 20**

21/29

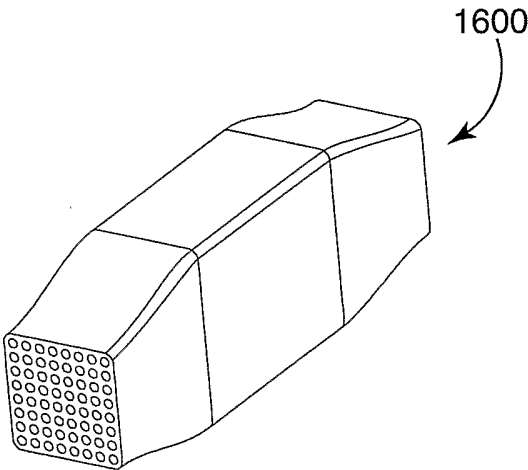


FIG. 21

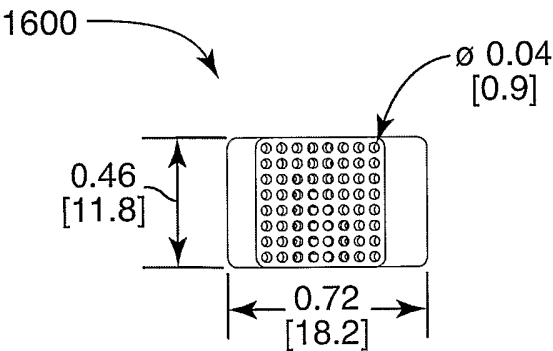


FIG. 22

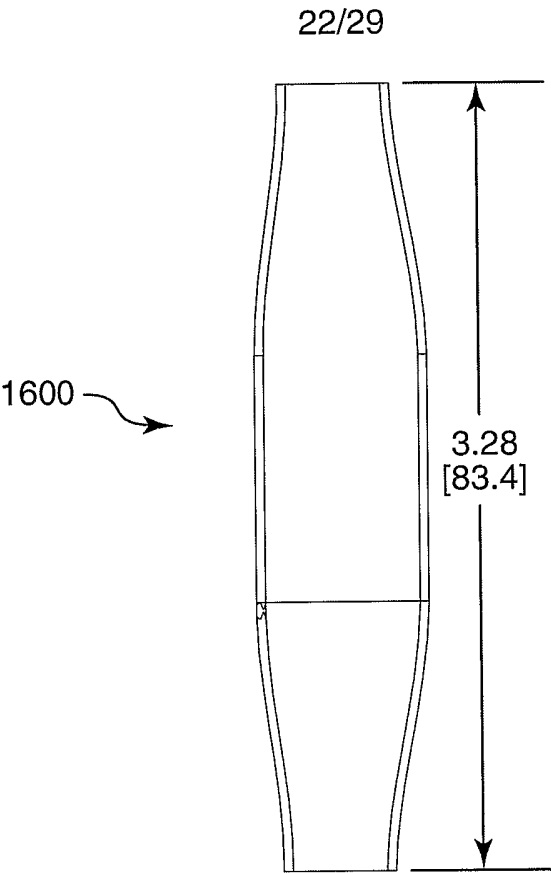


**FIG. 23**

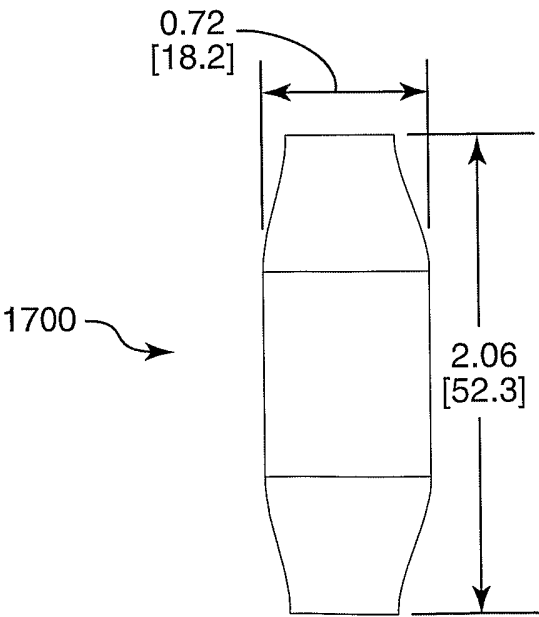


**FIG. 24**

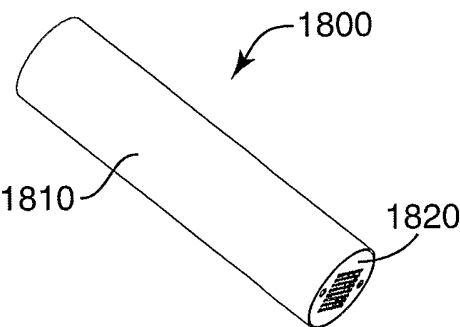


**FIG. 25**

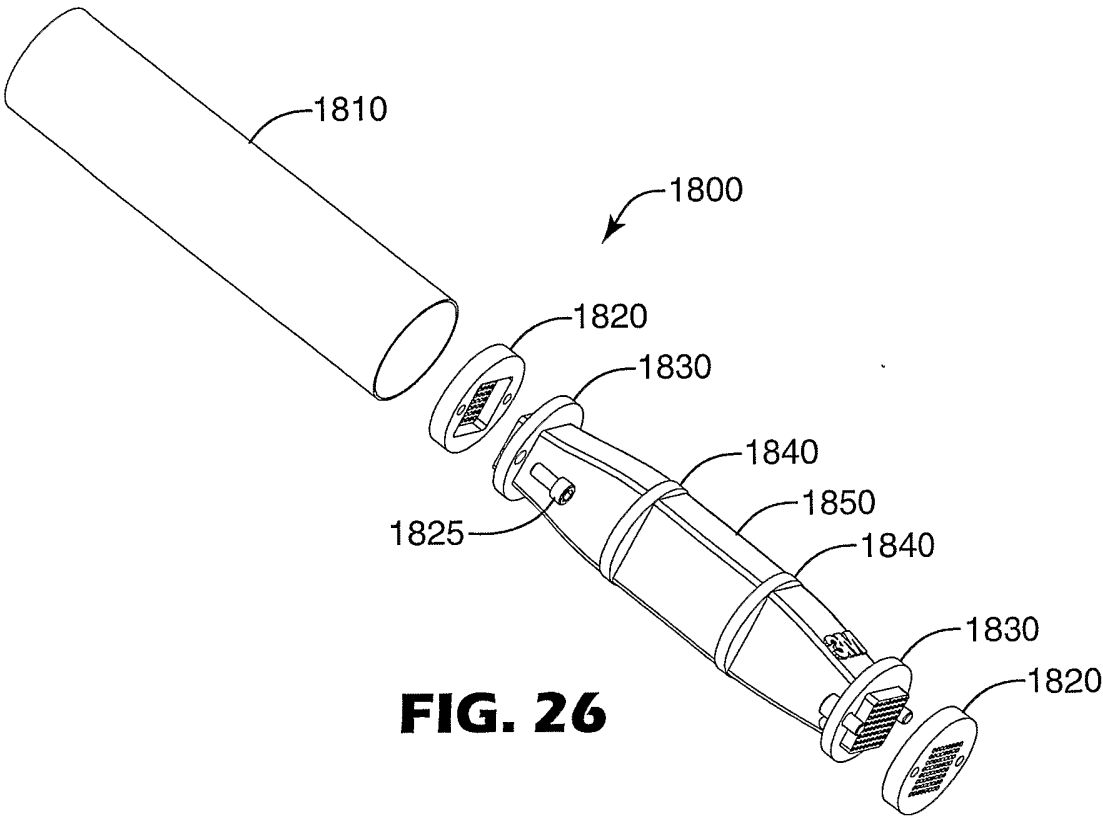


**FIG. 26**

24/29

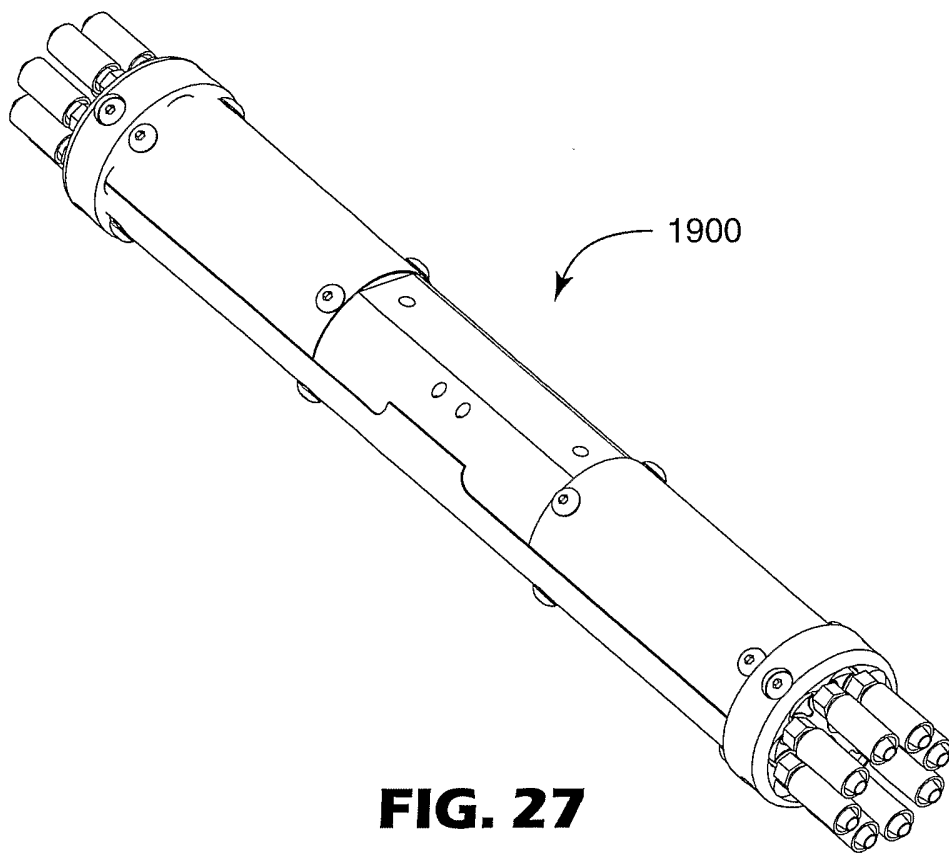


**FIG. 27**

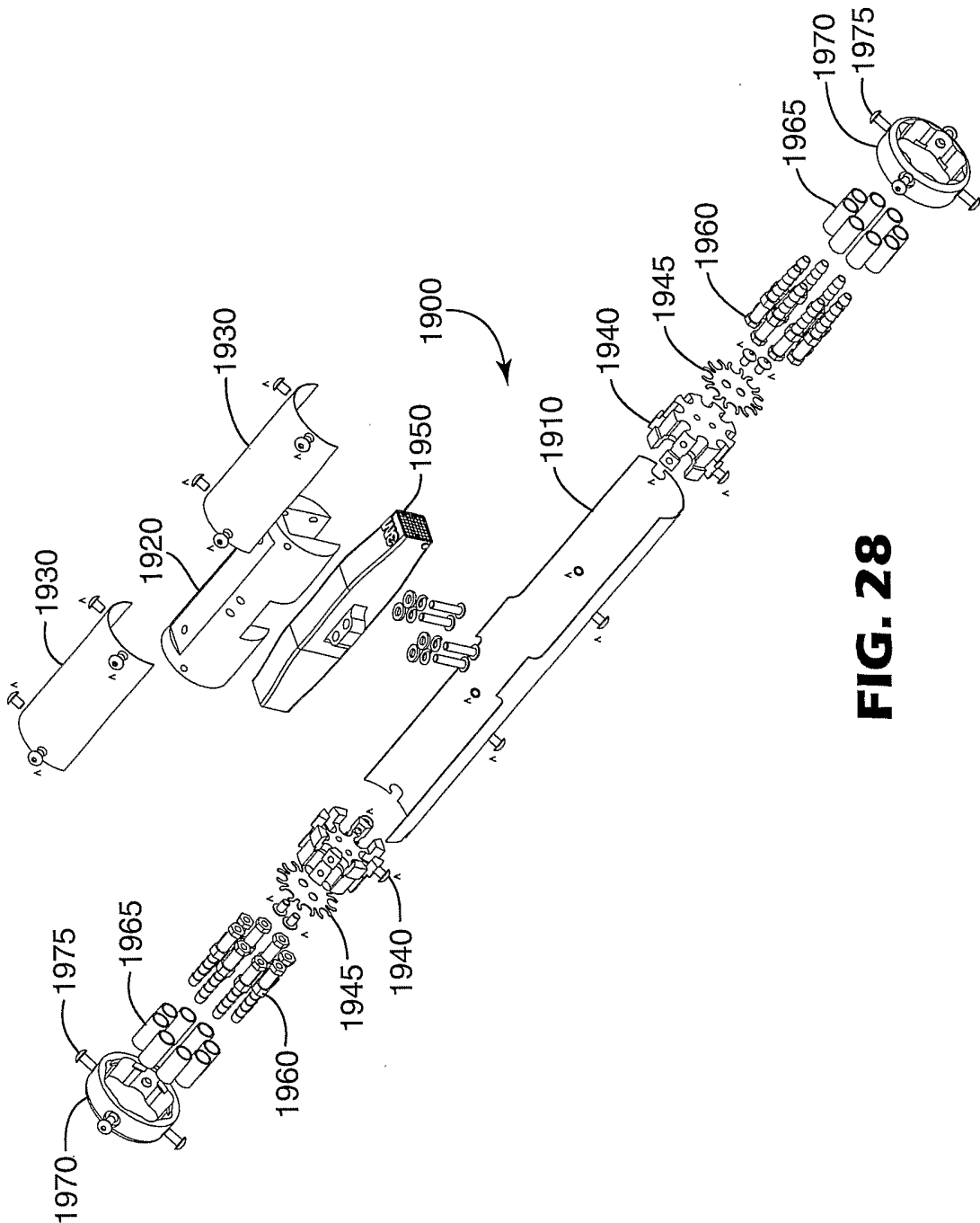


FIG. 28

26/29

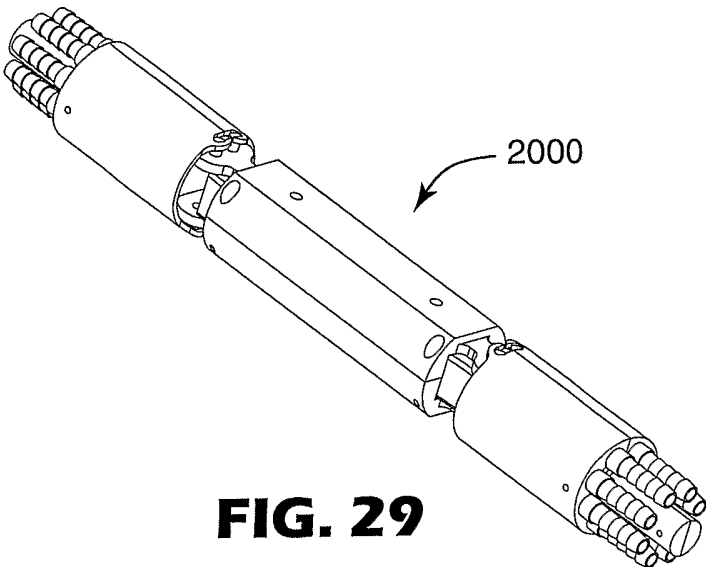


**FIG. 29**

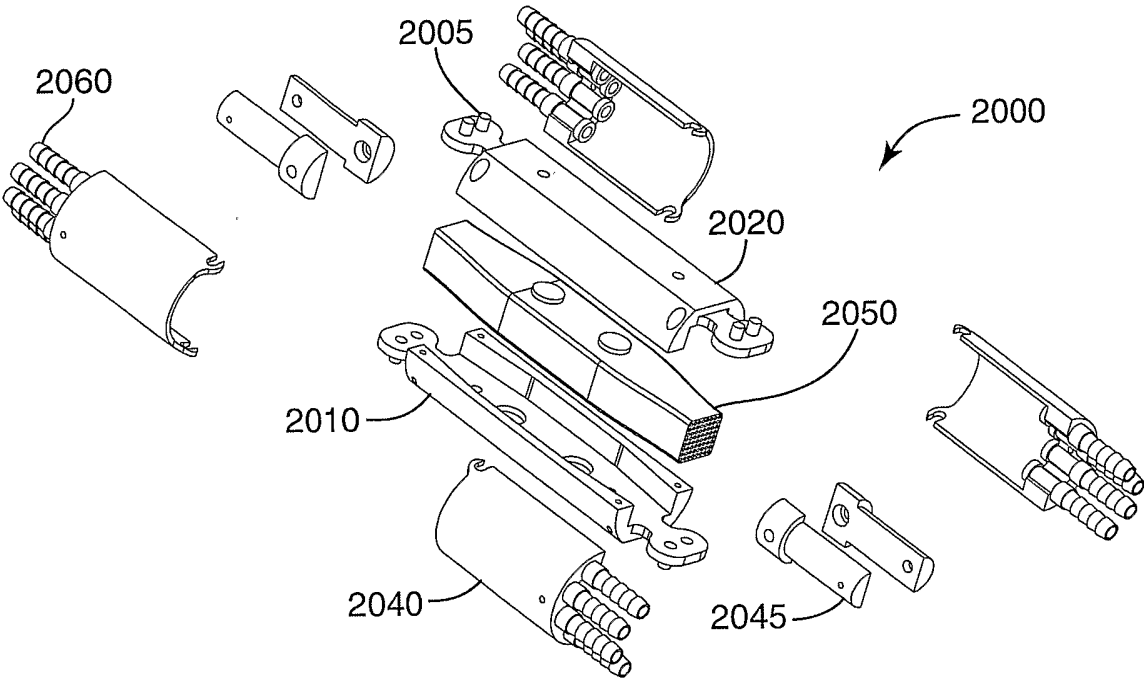


**FIG. 30**

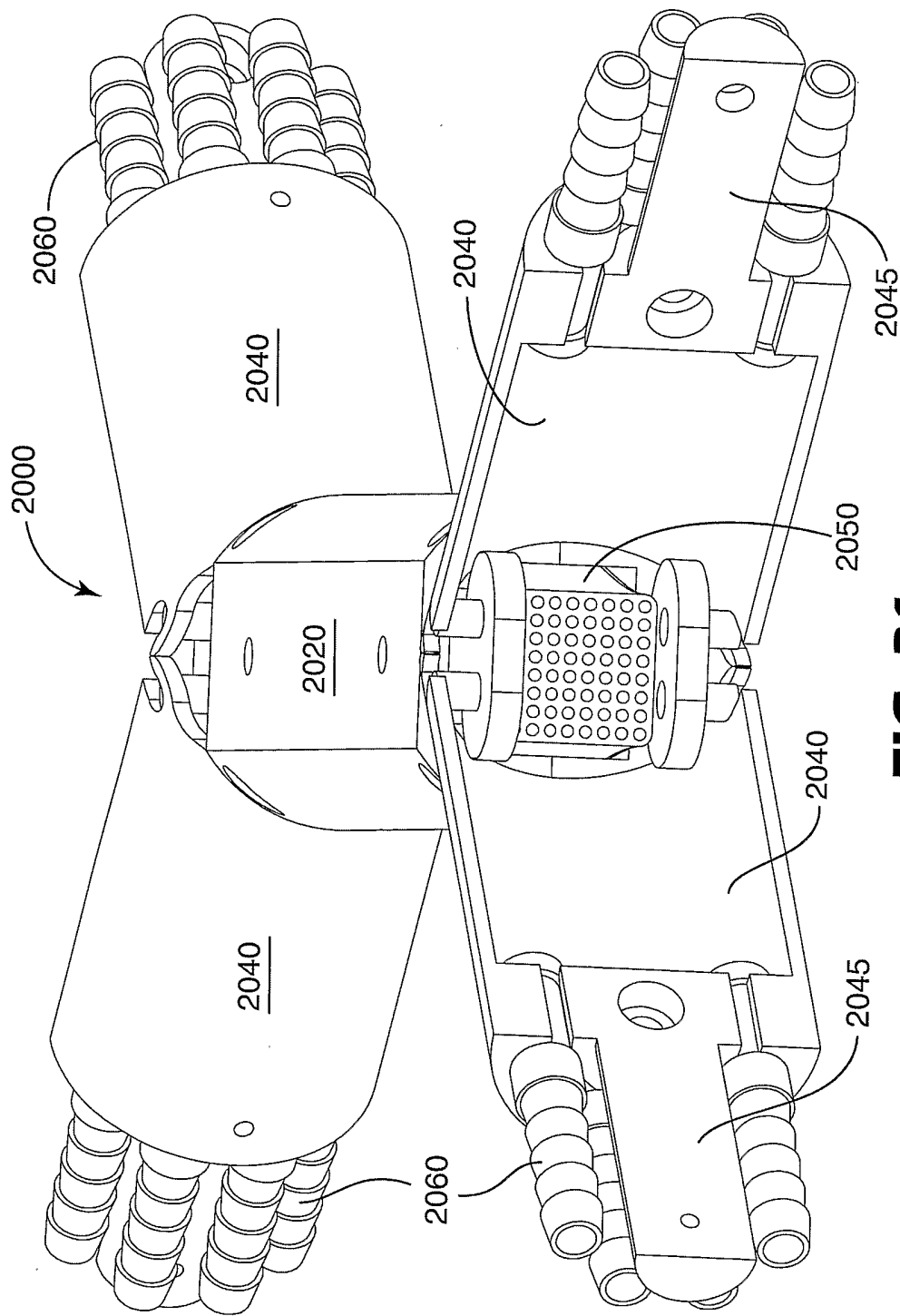
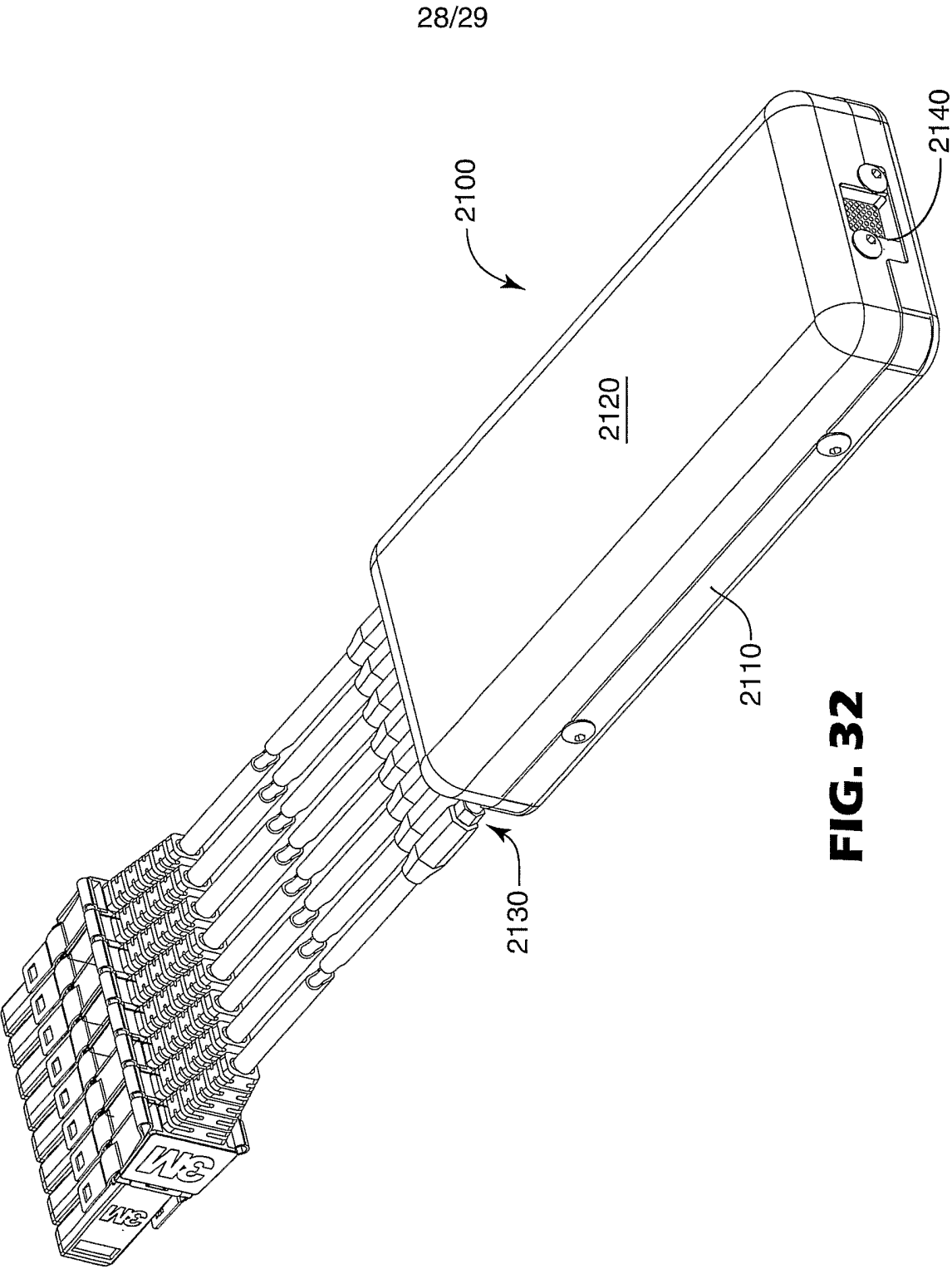


**FIG. 31**



29/29

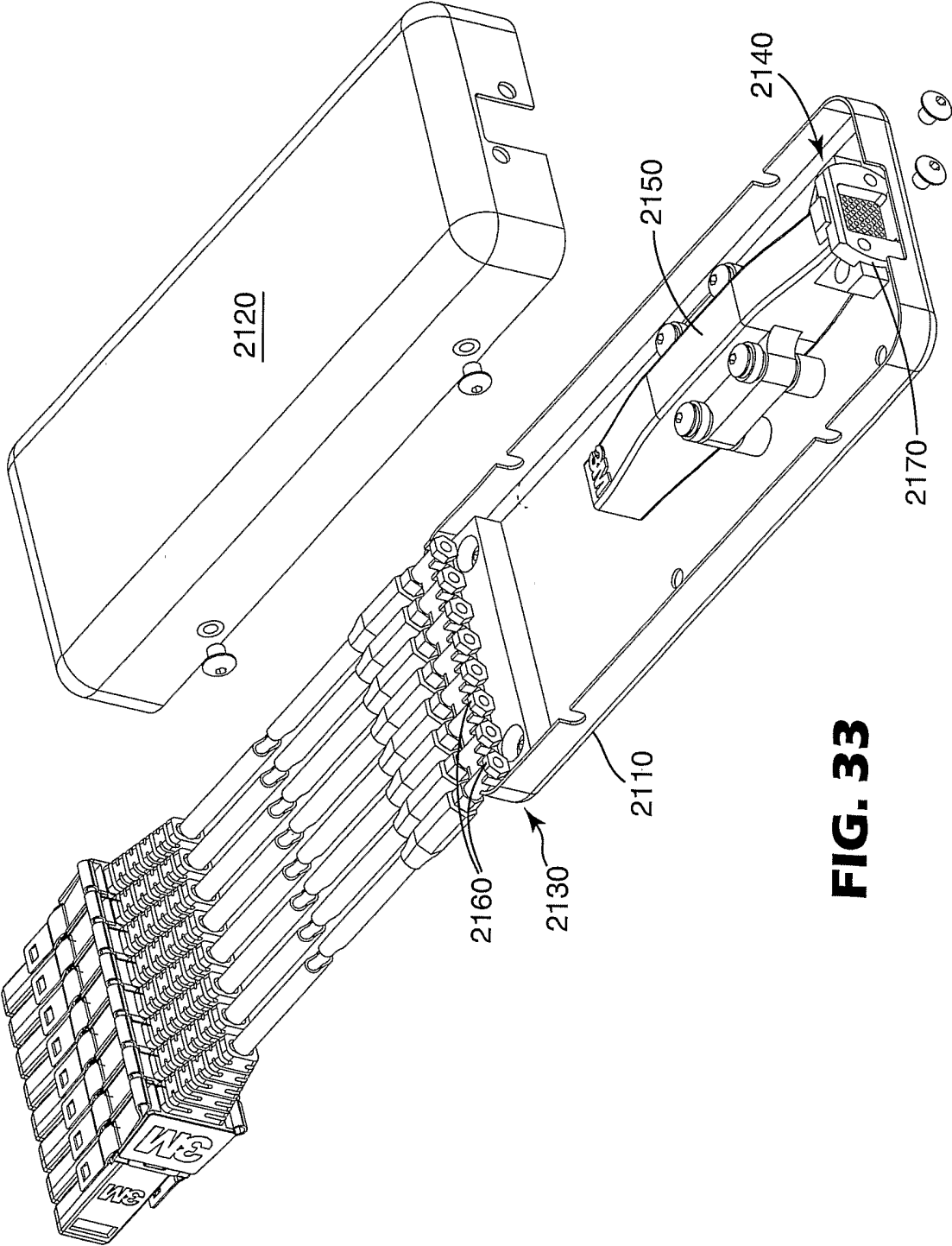


**FIG. 33**