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(71) Applicant *(for all designated States except US)*: CORNING CABLE SYSTEMS LLC [US/US]; Intellectual Property Department, SP-TI-3-1, Corning, NY 14831 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: LOGAN, Eric, R. [US/US]; 1136 38th Ave. NE, Hickory, NC 28601 (US).

(74) Agent: MONTGOMERY, C., Keith; Corning Cable Systems LLC, 800 17th Street NW, P.O. Box 489, Hickory, NC 28603 (US).

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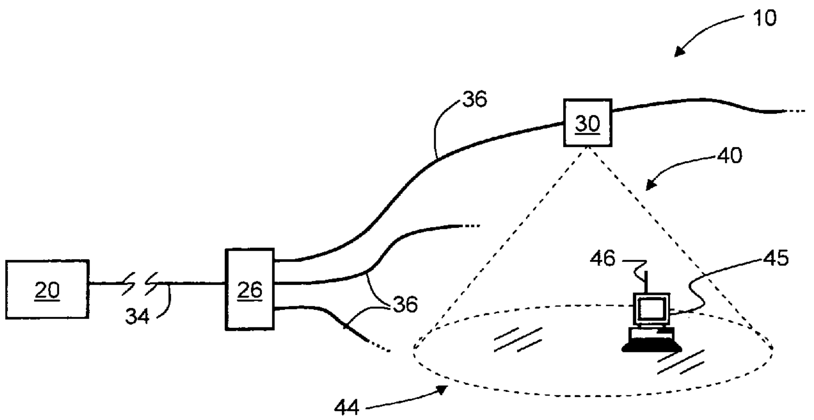


FIG. 1

(57) Abstract: A multi-port accumulator apparatus for a radio-over-fiber (RoF) wireless picocellular system that includes a housing that supports a tail cable port and a number of RoF transponder ports. The tail cable port is optically coupled to the RoF transponder ports so as to provide for optical transmission of uplink and downlink optical signals between the tail cable port and each of the transponder ports. The tail cable port is also electrically coupled to each transponder port so as to provide electrical power to each of the plurality of transponder ports. The multi-port accumulator supports two or more RoF transponders, one at each RoF transponder port. Each RoF transponder includes a directional antenna system that forms a picocellular coverage sub-area, with the combined sub-areas constituting a picocellular coverage area for the multi-port accumulator. The multi-port accumulator allows for the quick installation and deployment of large numbers of RoF transponders without having to individually connect each RoF transponder to a pair of downlink and uplink optical fibers carried by an optical fiber RF communication link.

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# MULTI-PORT ACCUMULATOR FOR RADIO-OVER-FIBER (ROF) WIRELESS PICOCELLULAR SYSTEMS

## BACKGROUND OF THE INVENTION

## *Field of the Invention*

[0001] The present invention relates generally to wireless communication systems, and in particular relates to transponders and transponder systems and methods used in optical-fiber-based wireless picocellular systems for radio-over-fiber (RoF) communication.

### *Technical Background*

[0002] Wireless communication is rapidly growing, with ever-increasing demands for high-speed mobile data communication. As an example, so-called "wireless fidelity" or "WiFi" systems and wireless local area networks (WLANs) are being deployed in many different types of areas (coffee shops, airports, libraries, etc.). Wireless communication systems communicate with wireless devices called "clients," which must reside within the wireless range or "cell coverage area" in order to communicate with the access point device.

[0003] One approach to deploying a wireless communication system involves the use of "picocells," which are radio-frequency (RF) coverage areas having a radius in the range from about a few meters up to about 20 meters. Because a picocell covers a small area, there are typically only a few users (clients) per picocell. Picocells also allow for selective wireless coverage in small regions that otherwise would have poor signal strength when covered by larger cells created by conventional base stations.

[0004] In conventional wireless systems, picocells are created by and centered on a wireless access point device connected to a head-end controller. The wireless access point device includes digital information processing electronics, an RF transmitter/receiver, and an antenna operably connected to the RF transmitter/receiver. The size of a given picocell is determined by the amount of RF power transmitted by the access point device, the receiver sensitivity, antenna gain and the RF environment, as well as by the RF transmitter/receiver sensitivity of the wireless client device. Client devices usually have a fixed RF receiver sensitivity, so that the above-mentioned properties of the access point device mainly determine the picocell size. Combining a number of access point devices connected to the head-end controller creates an array of picocells that cover an area called a "picocellular coverage area." A closely packed picocellular array provides high per-user data-throughput over the picocellular coverage area.

[0005] Prior art wireless systems and networks are wire-based signal distribution systems where the access point devices are treated as separate processing units linked to a central location. This makes the wireless system/network relatively complex and difficult to scale, particularly when many picocells need to cover a large region. Further, the digital information processing performed at the access point devices requires that these devices be activated and controlled by the head-end controller, which further complicates the distribution and use of numerous access point devices to produce a large picocellular coverage area.

[0006] Radio-over-Fiber (RoF) wireless picocellular systems utilized optical fibers to transmit the RF signals to RoF transponders that convert the RF optical signals to electrical RF signals and then to wireless electromagnetic (EM) signals, and vice versa. Unlike conventional wireless system access points, the RoF transponders generally do not require any signal processing capability, thereby simplifying the distribution of the RoF transponders to produce a large picocellular coverage area.

[0007] While RoF wireless picocellular systems are generally robust, there are some shortcomings. One shortcoming relates to the relative difficulty in manufacturing and deploying an optical fiber cable having a linear array of transponders. Each transponder needs to be optically coupled to an uplink optical fiber and a downlink optical fiber as well as to an electrical power line, usually via a "tether cable." This involves the tedious and time-consuming process of accessing the uplink and downlink optical fibers and the electrical power line in the cable, splicing the optical fibers and electrical power line, and then connecting them to the transponder. Another shortcoming of the linear array approach for distributing transponders is that the approach is not readily scalable once the system is deployed. This makes it difficult to quickly and inexpensively change the picocell coverage area to accommodate the changing needs or geometry of the particular wireless environment.

## SUMMARY OF THE INVENTION

[0008] One aspect of the invention is a multi-port accumulator apparatus for operably supporting two or more RoF transponders and for providing a connection to a tail cable that carries uplink and downlink optical signals and electrical power. The apparatus includes a housing and two or more RoF transponder ports supported by the housing, with each RoF transponder port configured to operably connect to one of the RoF transponders. The apparatus also includes a tail cable port supported by the housing and configured to operably connect to the tail cable. The tail cable port is optically and electrically connected to each RoF transponder port so as to provide the uplink and downlink optical signals and the electrical power to each RoF transponder.

[0009] Another aspect of the invention is a method of forming a RoF wireless picocellular coverage area. The method includes operably supporting two or more RoF transponders on a housing, and providing downlink optical signals for the RoF transponders to a tail cable port on the housing via a tail cable. The method further includes distributing the downlink optical signals through the housing to one or more of the RoF transponders so that the one or more RoF transponders contribute to forming a picocellular coverage area.

[0010] Another aspect of the invention is a multi-port accumulator apparatus for supporting a plurality of RoF transponders for a RoF wireless picocellular system. The apparatus includes a housing, and a plurality of RoF transponder ports supported by the housing. Each RoF transponder port is adapted to operably connect with one of the RoF transponders. The apparatus also includes a tail cable optically coupled within the housing to the plurality of RoF transponder ports so as to provide for optical transmission of uplink and downlink optical signals between the tail cable and the plurality of RoF transponder ports. The tail cable is also electrically coupled within the housing to the plurality of RoF transponder ports so as to provide electrical power to each of the plurality of RoF transponder ports.

[0011] Additional features and advantages of the invention are set forth in the detailed description that follows, and will be readily apparent to those skilled in the art from that description or recognized by practicing the invention as described herein, including the detailed description that follows, the claims, as well as the appended drawings.

[0012] It is to be understood that both the foregoing general description and the following detailed description present embodiments of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the invention and, together with the description, serve to explain the principles and operations of the invention.

[0013] Accordingly, various basic electronic circuit elements and signal-conditioning components, such as bias tees, RF filters, amplifiers, power dividers, etc., are not all shown in the Figures for ease of explanation and illustration. The application of such basic electronic circuit elements and components to the systems of the present invention will be apparent to one skilled in the art.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0014] **FIG. 1** is a schematic diagram of a generalized embodiment of an optical-fiber-based RoF wireless picocellular system showing a single transponder and its associated picocell and picocell coverage area;

[0015] **FIG. 2** is a detailed schematic diagram of an example embodiment of a head-end unit for the system of **FIG. 1**;

[0016] **FIG. 3** is a detailed schematic diagram of an example embodiment of the distribution unit and transponder of the system of **FIG. 1**;

[0017] **FIG. 4** is a close-up view of an alternative example embodiment for the transponder shown in **FIG. 3** that includes a transmitting antenna element and a receiving antenna element within the transponder housing along with reflectors that enhance the directivity of the antenna elements;

[0018] **FIG. 5** is a schematic perspective diagram of an example embodiment of a multi-port accumulator according to the present invention that has four transponder ports;

[0019] **FIG. 6** is a plan view of an example embodiment of the multi-port accumulator of **FIG. 5** with the top wall removed, showing the internal uplink and downlink optical fiber sections and the electrical power line sections that connect the tail cable port to the transponder ports;

[0020] **FIG. 7** is a side view of the multi-port accumulator of **FIG. 6** showing the tail cable connected to tail cable port;

[0021] **FIG. 8** is the same as **FIG. 7**, but with the sidewall removed to illustrate the optical and electrical connections between the tail cable port and one of the transponder ports;

[0022] **FIG. 9** and **FIG. 10** are the same as **FIG. 7** and **FIG. 8**, respectively, and illustrate an example embodiment of a pre-stubbed configuration of the multi-port accumulator and tail cable;

[0023] **FIG. 11** is a schematic diagram of an example embodiment of an RoF wireless picocellular system according to the present invention similar to that shown in **FIG. 1** but that utilizes a number of multi-port accumulators;

[0024] **FIG. 12** is a close-up plan view of one of the multi-port accumulators of **FIG. 11**, showing the associated picocellular coverage area as made up of four picocellular coverage sub-areas associated with the four transponders supported by the multi-port accumulator;

[0025] **FIG. 13** is an example embodiment of a transponder for use with the multi-port accumulator and that includes an antenna system with adjustable antenna directionality;

[0026] **FIG. 14** is a schematic plan view of an example embodiment of a multi-port accumulator having a hexagonal-shaped housing that supports six transponders; and

[0027] **FIG. 15** is a schematic plan view of an example embodiment of a multi-port accumulator having a triangular-shaped housing that supports three transponders.

## DETAILED DESCRIPTION OF THE INVENTION

[0028] Reference is now made in detail to certain embodiments of the invention, examples of which are illustrated in the accompanying drawings. Whenever possible, the same or analogous reference numbers are used throughout the drawings to refer to the same or like parts.

### *Generalized optical-fiber-based RoF wireless picocellular system*

[0029] **FIG. 1** is a schematic diagram of a generalized example embodiment of an optical-fiber-based RoF wireless picocellular system **10**. System **10** includes a head-end unit **20**, a distribution unit **26**, at least one RoF transponder unit ("transponder") **30**, a primary optical fiber RF communication link **34** that optically couples the head-end unit to the distribution unit, and at least one secondary optical fiber RF communication link **36** that couples one or more transponders to the distribution unit, thus establishing a connection between the transponder(s) and the head-end unit. In an example embodiment, optical fiber RF communication links **34** and **36** include at least one optical fiber, and preferably two optical fibers (e.g., uplink and downlink optical fibers, as discussed below). As discussed in detail below, system **10** is adapted to form a picocell **40** substantially centered about transponder **30**. One or more transponders **30** form a picocellular coverage area **44**. Distribution unit **26** is adapted to divide the primary optical fiber RF communication link **34** into a number of secondary RF optical fiber communication links (hereinafter, "tail cables") **36** that facilitate distributing a number of transponders **30** throughout a given infrastructure.

**[0030]** Head-end unit **20** is adapted to perform or to facilitate any one of a number of RoF applications, such as radio-frequency identification (RFID), wireless local-area network (WLAN) communication, or cellular phone service to provide non-limiting examples. Shown within picocell **40** is a client device **45** in the form of a computer. Client device **45** includes an antenna **46** (e.g., a wireless card) adapted to receive and/or send wireless electromagnetic RF signals.

**[0031]** **FIG. 2** is a detailed schematic diagram of an example embodiment of head-end unit **20** of system **10** of **FIG. 1**. Head-end unit **20** includes a service unit **50** that provides electrical RF service signals for a particular wireless service or application. In an example embodiment, service unit **50** provides electrical RF service signals by passing (or conditioning and then passing) such signals from one or more outside networks **52**. In a particular example embodiment, this includes providing WLAN signal distribution as specified in the IEEE 802.11 standard, i.e., in the frequency range from 2.4 to 2.5 GHz and from 5.0 to 6.0 GHz. In another example embodiment, service unit **50** provides electrical RF service signals by generating the signals directly. In another example embodiment, service unit **50** coordinates the delivery of the electrical RF service signals between client devices within picocellular coverage area **44**.

**[0032]** Service unit **50** is electrically coupled to an electrical-to-optical (E/O) converter **60** that receives an electrical RF service signal from the service unit and converts it to a corresponding optical signal. In an example embodiment, E/O converter **60** includes a laser suitable for delivering sufficient dynamic range for the RF-over-fiber applications of the present invention, and optionally includes a laser driver/amplifier electrically coupled to the laser. Examples of suitable lasers for E/O converter **60** include laser diodes, distributed feedback (DFB) lasers, Fabry-Perot (FP) lasers, and vertical cavity surface emitting lasers (VCSELs).

**[0033]** Head-end unit **20** also includes an optical-to-electrical (O/E) converter **62** electrically coupled to service unit **50**. O/E converter **62** receives an optical RF service signal and converts it to a corresponding electrical signal. In an example embodiment, O/E converter is a photodetector, or a photodetector electrically coupled to a linear amplifier. E/O converter **60** and O/E converter **62** constitute a "converter pair unit" **66**.

**[0034]** In an example embodiment, service unit **50** includes an RF signal modulator/demodulator (M/D) unit **70** that generates an RF carrier of a given frequency and then modulates RF signals onto the carrier, and that also demodulates received RF signals. Service unit 50 also includes a digital signal processing unit ("digital signal processor") **72**, a central processing unit (CPU) **74** for processing data and otherwise performing logic and computing operations, and a memory unit **76** for storing data, such as RFID tag information or data to be transmitted over the WLAN. In an example embodiment, the different frequencies associated with the different signal channels are created by M/D unit **70** generating different RF carrier frequencies based on instructions from CPU **74**. Also, as described below, the common frequencies associated with a particular combined picocell are created by M/D unit **70** generating the same RF carrier frequency.

**[0035]** **FIG. 3** is a detailed schematic diagram of an example embodiment of the portion of system **10** of **FIG. 1** that includes distribution unit **26** and transponder **30**. Transponder **30** includes a converter pair **66**, wherein the E/O converter **60** and the O/E converter **62** therein are electrically coupled to an antenna system **100** via an RF signal-directing element **106**, such as a circulator. Signal-directing element **106** serves to direct the downlink and uplink electrical RF service signals, as discussed below. In an example embodiment, antenna system **100** includes one or more directional patch antennas, such as disclosed in U.S. Patent Application Serial No. 11/504,999 filed August 16, 2006, which patent application is incorporated herein by reference. In another example embodiment, antenna system has enhanced directionality, such as disclosed in U.S. Patent Application Serial No. 11/703,016 filed February 6, 2007, which patent application is incorporated by reference herein. Antenna system **100** is discussed in greater detail below. Transponder **30** also includes a housing **102** that in an example embodiment houses some or all of the various transponder elements. In an example embodiment, some or all of antenna system **100** lies outside of housing **102**. In an example embodiment, housing **102** houses only the elements making up converter pair unit **66**.

**[0036]** **FIG. 4** is a close-up view of an alternative example embodiment for transponder **30** wherein antenna system **100** includes two antennae: a transmitting antenna **101T** electrically coupled to O/E converter **62**, and a receiving antenna **101R** electrically coupled to E/O converter **60**. The two-antenna embodiment obviates the need for RF signal-directing element **106**. Note also that the example embodiment of transponder **30** in **FIG. 3** includes DC power converter **180** within converter pair unit **66**, and that antenna system **100** is within housing **102**. **FIG. 4** also illustrates an example embodiment wherein transponder **30** includes a connector **31** adapted to connect to a corresponding connector plug **37** on tail cable **36**. **FIG. 4** also illustrates an example embodiment that includes at least one antenna reflector **104** arranged relative to antenna system **100** so as to enhance the directionality of the antenna system, such as described in aforementioned U.S. Patent Application Serial No. 11/703,016.

**[0037]** Transponders **30** of the present invention differ from the typical access point device associated with non-RoF wireless communication systems in that the preferred embodiment of the transponder has just a few signal-conditioning elements and no digital information processing capability. Rather, the information processing capability is located remotely in head-end unit **20**, and in a particular example, in service unit **50**. This allows transponder **30** to be very compact and virtually maintenance free. In addition, the preferred example embodiment of transponder **30** consumes very little power, is transparent to RF signals, and does not require a local power source, as described below.

**[0038]** With reference to **FIG. 2** and **FIG. 3** , in an example embodiment, optical fiber RF communication link **34** and tail cable **36** includes at least one downlink optical fiber **136D** and at least one uplink optical fiber **136U**. Downlink and uplink optical fibers **136D** and **136U** in optical fiber RF communication link **34** optically couple converter pair **66** at head-end unit **20** to distribution unit **26**, while the downlink and uplink optical fibers in tail cable **36** connect the distribution unit **26** to the converter pair at transponder **30**. Thus, each transponder **30** is optically coupled to head-end unit **20**.

**[0039]** In an example embodiment, the optical-fiber-based wireless picocellular system **10** of the present invention employs a known telecommunications wavelength, such as 850 nm, 1300 nm, or 1550 nm. In another example embodiment, system **10** employs other less common but suitable wavelengths such as 980 nm.

**[0040]** Example embodiments of system **10** include either single-mode optical fiber or multimode optical fiber for downlink and uplink optical fibers **136D** and **136U**. The particular type of optical fiber depends on the application of system **10**. For many in-building deployment applications, maximum transmission distances typically do not exceed 300 meters. The maximum length for the intended RoF transmission needs to be taken into account when considering using multi-mode optical fibers for downlink and uplink optical fibers **136D** and **136U**. For example, it has been shown that a 1400 MHz.km multi-mode fiber bandwidth-distance product is sufficient for 5.2 GHz transmission up to 300 m.

**[0041]** In an example embodiment, the present invention employs 50 μm multi-mode optical fiber for the downlink and uplink optical fibers **136D** and **136U**, and E/O converters **60** that operate at 850 nm using commercially available VCSELs specified for 10 Gb/s data transmission. In a more specific example embodiment, OM3 50 μm multi-mode optical fiber is used for the downlink and uplink optical fibers **136D** and **136U**.

**[0042]** Wireless system **10** also includes a power supply **160** that generates an electrical power signal **162**. Power supply **160** is electrically coupled to head-end unit **20** for powering the power-consuming elements therein. In an example embodiment, an electrical power line **168** runs through the head-end unit and through distribution unit **26** to each transponder **30** to power E/O converter **60** and O/E converter **62** in converter pair **66**, the optional RF signal-directing element **106** (unless element **106** is a passive device such as a circulator), and any other power-consuming elements (not shown). Alternatively, electrical power line **168** runs from distribution unit **26** that also optionally includes a power supply **160** (**FIG. 3**). In an example embodiment, electrical power line **168** includes two wires **170** and **172** that carry a single voltage and that are electrically coupled to a DC power converter **180** at transponder **30**. DC power converter **180** is electrically coupled to E/O converter **60** and O/E converter **62,** and changes the voltage or levels of electrical power signal **162** to the power level(s) required by the power-consuming components in transponder **30**. In an example embodiment, DC power converter **180** is either a DC/DC power converter, or an AC/DC power converter, depending on the type of power signal **162** carried by electrical power line **168**. In an example embodiment, electrical power line **168** includes standard electrical-power-carrying electrical wire(s), such as a twisted copper pair (e.g., 18-26 AWG (American Wire Gauge)) used in standard telecommunications and other applications. In another example embodiment, electrical power line **168** (dashed line) runs directly from power supply **160** to transponder **30** rather than from or through head-end unit **20**. In another example embodiment, electrical power line **168** includes more than two wires and carries multiple voltages.

[0043] In an example embodiment, head-end unit **20** is operably coupled to an outside network **52** via a network link **53** (**FIG. 2**).

*Multi-port accumulator*

[0044] As mentioned above, a RoF wireless picocellular system that employs a linear array of transponders has some shortcomings relating to its manufacture and deployment. Accordingly, an aspect of the present invention addresses these and other shortcomings by consolidating transponders **30** into a more compact and more easily manufacturable and deployable RoF wireless picocellular system.

[0045] **FIG. 5** is a schematic perspective diagram of an example embodiment of a multi-port accumulator apparatus **200** ("multi-port accumulator") according to the present invention. Multi-port accumulator **200** includes a housing **202** having a number of sidewalls **204**, a top wall **206** and a bottom wall **208**. Housing **202** includes two or more transponder connector ports **212** formed in corresponding two or more of sidewalls **204**. Multi-port accumulator **200** of **FIG. 5** illustrates an example embodiment of a rectangular (square) housing **202** having four sidewalls **204A**, **204B**, **204C** and **204D** with four associated RoF transponder connector ports ("transponder ports") **212A**, **212B**, **212C** and **212D**. Housing **202** also includes a tail cable port **214** on top wall **206**. Housing **202** can generally be made of a number of suitable materials, such as metal or plastic.

[0046] **FIG. 6** is a plan view of multi-port accumulator **200** with top wall **206** removed, showing tail cable connector port ("tail cable port") **214** and four transponders **30A**, **30B**, **30C** and **30D** operably coupled to the device via associated transponder ports **212A**, **212B**, **212C** and **212D**. Device **200** includes, for each transponder port **212**, optical fiber sections **236U** and **236D** that correspond to uplink and downlink optical fibers **136U** and **136D** in tail cable **36**. Thus, each optical fiber section **236UA** and **236DA** is optically connected at one end to transponder port **212A** and at its opposite end to tail cable port **214**, etc.

[0047] Likewise, device **200** includes for each transponder port **212** an electrical power line section **268** connected at one end to the transponder port and at its opposite end to tail cable port **214**. Thus, electrical power line section **268A** electrically connects transponder port **212A** to tail cable port **214**, etc.

[0048] **FIG. 7** is a side view of the multi-port accumulator **200** of **FIG. 6**. showing the connection of tail cable **36** to the multi-port accumulator using tail cable connector plug **37** connected to tail cable port **214**. **FIG. 8** is a side view of device **200** as shown in **FIG. 7** with sidewall **204B** removed, illustrating the optical and electrical connections between tail cable port **214** and transponder port **212C** via optical fiber sections **236UC**, **236DC** and electrical power line section **168C**. The other transponder ports **212A**, **212B** and **212C** are similarly connected to tail cable port **214**.

**[0049]** **FIG. 9** and **FIG. 10** are similar to **FIG. 7** and **FIG. 8**, respectively, and illustrate an example embodiment of multi-port accumulator **200** and tail cable **36** in a pre-stubbed configuration that does not require tail cable port **214**. In the pre-stubbed configuration embodiment, rather than using separate optical fiber sections **236U** and **236D** to connect to each RF transponder port **212**, uplink and downlink optical fibers **136U** and **136D** are stripped out of the tail cable and connected directly to associated RF transponder ports.

**[0050]** In an example embodiment, tail cable **36** includes a connector plug **37** at the end opposite multi-port accumulator **200** for connecting to distribution unit **26** at a mating connector socket **27** (**FIG. 3**). Similarly, further embodiments of the present invention comprise tail cables, similar to tale cable **36**, that include a connector plug, similar to the connector plug **37**, rather than cable ports, such as cable ports **212A-212D**, to connect the transponders, such as transponders **30**. Even further embodiments of the present invention include multi-port accumulators with permanently mounted cable assemblies to which transponders are permanently connected.

***General method of operation using multi-port accumulator***

**[0051]** **FIG. 11** is a schematic diagram of an example embodiment of an RoF wireless picocellular system **10** similar to that shown in **FIG. 1** but that utilizes one or more multi-port accumulators **200** according to the present invention to deploy transponders **30**. Note that the lower-most multi-port accumulator in **FIG. 11** is in the aforementioned pre-stubbed configuration discussed in connection with **FIG. 9** and **FIG. 10**.

**[0052]** With reference to **FIG. 11** as well as to **FIG. 2**, in the operation of system **10** service unit **50** in head-end unit **20** generates an electrical downlink RF service signal **SD** ("electrical signal **SD**") corresponding to its particular application. In an example embodiment, this is accomplished by digital signal processor **72** providing RF M/D unit **70** with an electrical signal (not shown) that is modulated onto an RF carrier to generate a desired electrical signal **SD**.

[0053] Electrical signal **SD** is received by E/O converter **60**, which converts this electrical signal into a corresponding optical downlink RF signal **SD'** ("optical signal **SD'** "), which is then directed to a number (e.g., five) of downlink optical fibers **134D** of primary optical fiber RF communication link **34.** It is noted here that in an example embodiment optical signal **SD'** is tailored to have a given modulation index. Further, in an example embodiment the modulation power of E/O converter **60** is controlled (e.g., by one or more gain-control amplifiers, not shown) to vary the transmission power from antenna system **100**. In an example embodiment, the amount of power provided to antenna system **100** is varied to define the size of picocell coverage area **44** of the associated picocell **40.**

[0054] Optical signal **SD'** travels over downlink optical fibers **134D** to distribution unit **26**, which serves to direct signals **SD'** to the downlink optical fibers **136D** of the five tail cables **36**. Optical signal **SD'** then travels over the respective tail cables **36** to the associated multi-port accumulator **200**. Optical signals **SD'** in each downlink optical fiber **136D** are then directed to the associated downlink optical fiber section **236D** via tail cable port **214** and thus to the associated transponder connector port **212**. Each optical signal **SD'** is then received by O/E converter **62** in the associated transponder **30**. Each O/E converter **62** converts optical signal **SD'** back into electrical signal **SD**, which then travels to signal-directing element **106**. Signal-directing element **106** then directs electrical signal **SD** to antenna system **100**. Electrical signal **SD** is fed to antenna system **100**, causing it to radiate a corresponding electromagnetic downlink RF signal **SD"** ("electromagnetic signal **SD"** ") to create an associated picocellular coverage area.

[0055] **FIG. 12** is a close-up plan view of one of the multi-port accumulators **200** of **FIG. 11**, showing the picocellular coverage area **44** associated with the multi-port accumulator. Because antenna system **100** of each transponder **30** supported by multi-port accumulator **200** is directional, picocellular coverage area **44** is made up of two or more sub-areas **44A**, **44B**,.. etc. – such as sub-areas **44A**, **44B**, **44C** and **44D** as shown in **FIG. 12**. If a client device **45** is within one of the picocellular coverage sub-areas (e.g., sub-area **44A** as shown in **FIG. 12**), the client device will receive electromagnetic signal **SD"** via client device antenna **46** (**FIG. 1**), which may be part of a wireless card, or a cell phone antenna, for example. Antenna **46** converts electromagnetic signal **SD"** into electrical signal **SD** in the client device (signal **SD** is not shown therein). Client device **45** then processes electrical signal **SD**, e.g., stores the signal information in memory, displays the information as an e-mail or text message, etc.

[0056] In an example embodiment, client device **45** generates an electrical uplink RF signal **SU** (not shown in the client device), which is converted into an electromagnetic uplink RF signal **SU"** ("electromagnetic signal **SU"** ") by antenna **46**.

[0057] Because client device **45** is located within picocellular coverage sub-area **44A**, electromagnetic signal **SU"** is detected by antenna system **100** of the transponder **30A**. Antenna system **100** converts electromagnetic signal **SU"** back into electrical signal **SU**. Electrical signal **SU** is directed by signal-directing element **106** to E/O converter **60**, which converts this electrical signal into a corresponding optical uplink RF signal **SU'** ("optical signal **SU'** "), which is then directed into uplink optical fiber section **236U** at transponder port **212A**. Optical signal **SU'** travels over optical fiber section **236U** to tail cable port **214**, which serves to direct this optical signal onto the associated uplink optical fiber **136U** of the associated tail cable **36** connected to the tail cable port.

[0058] Optical signal **SU'** travels over uplink optical fiber **136U** to distribution unit **26**, where it is directed to the associated uplink optical fiber **134U** of primary RF optical fiber communication link **134**. Optical signal **SU'** then travels over primary RF optical fiber communication link **134** to head-end unit **20**, where it is received by O/E converter **62**. O/E converter **62** converts optical signal **SU'** back into electrical signal **SU**, which is then directed to service unit **50**. Service unit **50** receives and processes signal **SU**, which in an example embodiment includes one or more of the following: storing the signal information; digitally processing or conditioning the signal; sending the signal on to one or more outside networks **52** via network links **224**; and sending the signal to one or more client devices **45** in one or more of the other picocellular coverage areas **44** or sub-areas **44A**, **44B**, etc. In an example embodiment, the processing of signal **SU** includes demodulating this electrical signal in RF signal M/D unit **70**, and then processing the demodulated signal in digital signal processor **72**.

***Transponder with adjustable antenna system directivity***

[0059] **FIG. 13** is an example embodiment of transponder **30** that includes an antenna system **100** that has adjustable directivity. Transponder **30** of **FIG. 13** includes two or more antenna elements **101** such as the three antenna elements **101A**, **101B** and **101C** shown, each having a different directivity (i.e., EM radiation pattern). Antenna elements **101** are electrically connected to an antenna switch **300** that switches among the antenna element(s) **101** of antenna system **100** to be used.

[0060] In an example embodiment, antenna element **101A** is configured to provide coverage for all or substantially all of picocell coverage area **44**, antenna element **101B** is configured to cover two picocell coverage sub-areas (say, sub-areas **44A** and **44B**), while antenna element **101C** is configured to cover picocell coverage sub-area **44A**. This allows for multi-port accumulator **200** to form some or all of picocell coverage area **44** using one, some or all of transponders **30** of multi-port accumulator **200**. In an example embodiment, antenna switch **300** includes an antenna **302** and is configured to be switchable via a wireless switching signal **SS** received by antenna **302**. In another example embodiment, switching signal **SS** is non-wireless and originates from head-end unit **20** or from distribution unit **26**.

***Other multi-port accumulator housing geometries***

[0061] For the sake of illustration, multi-port accumulator **200** is described above in connection with a rectangular-shaped housing **202** that supports four transponders **30**. **FIG. 14** is a schematic plan view of an example embodiment of a multi-port accumulator **200** having a hexagonal-shaped that operably supports six transponders **30**. Likewise, **FIG. 15** is a schematic plan view of an example embodiment of a multi-port accumulator **200** having a triangular-shaped housing that operably supports three transponders **30**. Further embodiments of the present invention include alternative accumulators comprising any number of transponders in any geometric arrangement.

[0062] It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A multi-port accumulator apparatus for operably supporting two or more radio-over-fiber (RoF) transponders and for providing a connection to a tail cable that carries uplink and downlink optical signals and electrical power, comprising:

a housing;

two or more RoF transponder ports supported by the housing, with each RoF transponder port configured to operably connect to one of the RoF transponders;

a tail cable port supported by the housing and configured to operably connect to the tail cable, the tail cable port being optically and electrically connected to each RoF transponder port so as to provide the uplink and downlink optical signals and the electrical power to each RoF transponder.

2. The apparatus of claim 1, wherein:

the tail cable port is adapted to receive two or more external pairs of uplink and downlink optical fibers carried by the tail cable;

the tail cable port is optically coupled to the two or more RoF transponder ports via respective two or more internal pairs of uplink and downlink optical fiber sections; and

the tail cable port is configured to optically couple the external pairs of uplink and downlink optical fibers to the internal pairs of uplink and downlink optical fibers.

3. The apparatus of claim 2, wherein:

the tail cable port is adapted to receive an external electrical power line carried by the tail cable and that carries the electrical power;

the tail cable port is electrically coupled to the two or more RoF transponder ports via respective two or more internal electrical power line sections; and

the tail cable port is configured to electrically couple the external electrical power line to the two or more internal electrical power line sections so as to provide electrical power to each of the RoF transponders.

4. The apparatus of claim 1, wherein the housing has four sidewalls and four RoF transponder ports, with one transponder port supported by each sidewall.

5. The apparatus of claim 1, wherein the apparatus has associated therewith a picocell coverage area made up of two or more picocell coverage sub-areas respectively formed by the two or more RoF transponders.

6. The apparatus of claim 1, wherein at least one of the RoF transponders includes an antenna system having an adjustable antenna directivity.

7. The apparatus of claim 1, wherein at least one of the RoF transponders includes a patch antenna.

8. An RoF wireless picocellular system, comprising:

two or more multi-port accumulator apparatuses according to claim 1, with each multi-port accumulator apparatus optically coupled to a corresponding one of the tail cables.

9. The RoF wireless picocellular system of claim 8, further including:

a head-end unit configured to generate downlink optical signals and to receive uplink optical signals; and

a distribution unit optically coupled to the head-end unit and each tail cable so as to distribute the uplink and downlink optical signals between the transponders of each multi-port accumulator apparatus and the head-end unit.

10. A method of forming a radio-over-fiber (RoF) wireless picocellular coverage area, comprising:

operably supporting two or more RoF transponders on a housing;

providing downlink optical signals for the two or more RoF transponders to a tail cable port on the housing via a tail cable; and

distributing the downlink optical signals through the housing to one or more of the RoF transponders so that the one or more RoF transponders contribute to forming a picocellular coverage area.

11. The method of claim 10, wherein each RoF transponder receives the downlink optical signals and forms a picocellular coverage sub-area that constitutes a portion of the picocellular coverage area.

12. The method of claim 10, further including:

operably supporting the two or more RoF transponders at RoF transponder ports that are optically and electrically coupled to the tail cable port.

13. The method of claim 12, further including:

carrying electrical power in the tail cable in an electrical power line; and

distributing electrical power through the housing via electrical power line sections connected to the tail cable port and each of the RoF transponder ports so as to power each of the RoF transponders.

14. The method of claim 10, wherein each RoF transponder includes an antenna system, and further including adjusting the directivity of at least one of the antenna systems to adjust the corresponding RoF transponder's contribution to the picocellular coverage area.

15. A multi-port accumulator apparatus for supporting a plurality of RoF transponders for a radio-over-fiber (RoF) wireless picocellular system, comprising:

a housing;

a plurality of RoF transponder ports supported by the housing, with each RoF transponder port adapted to operably connect with one of the RoF transponders;

a tail cable optically coupled within the housing to the plurality of RoF transponder ports so as to provide for optical transmission of uplink and downlink optical signals between the tail cable and the plurality of RoF transponder ports; and

wherein the tail cable is electrically coupled within the housing to the plurality of RoF transponder ports so as to provide electrical power to each of the plurality of RoF transponder ports.

16. The apparatus of claim 15, further including one RoF transponder operably connected to each RoF transponder port.

17. The apparatus of claim 16, wherein each RoF transponder has a directional antenna system configured to form an associated picocellular coverage sub-area that makes up a picocellular coverage area formed by two or more of the RoF transponders.

18. The apparatus of claim 15, further including:

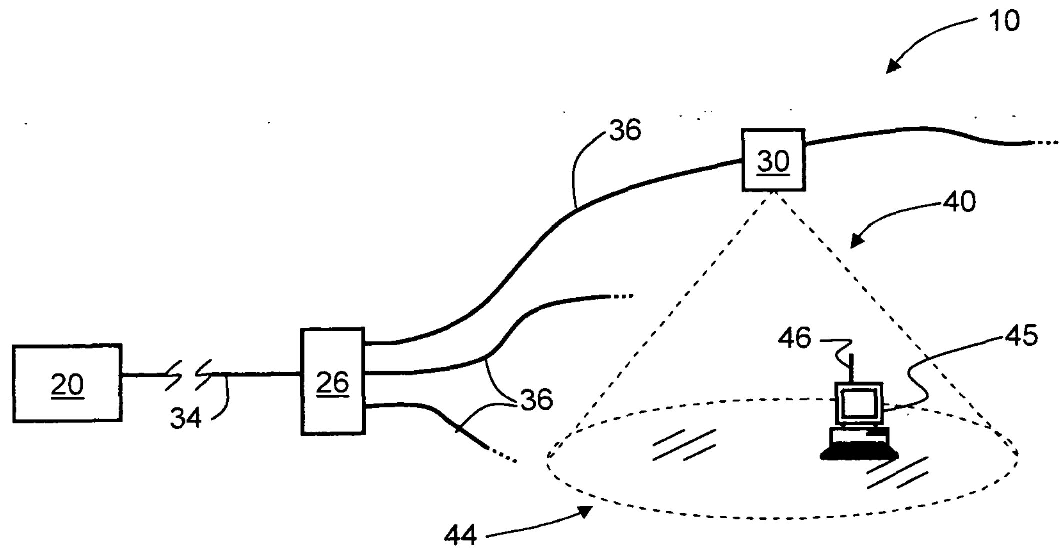
a tail cable port supported by the housing and optically and electrically coupled to each RoF transponder port;

a tail cable plug operably fixed to the tail cable at a tail cable end; and

wherein the tail cable is operably connected to the tail cable port via the tail cable plug.

19. An RoF wireless picocellular system, comprising two or more of the apparatuses of claim 18.

20. The apparatus of claim 18, wherein each RoF transponder port is optically coupled to the tail cable port via downlink and uplink optical fiber sections internal to the housing.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36
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46
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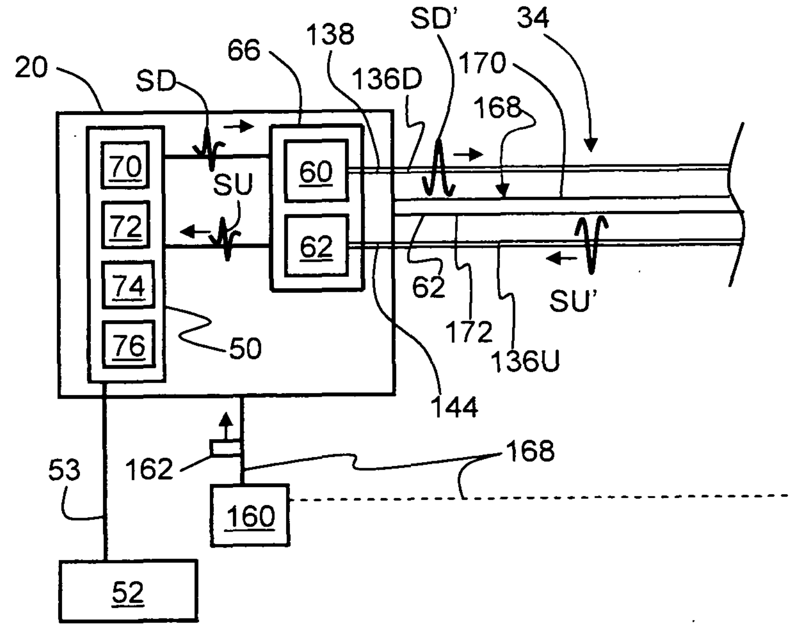
26
34
36
44

FIG. 1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SU'
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136U
144
53
162
168
160
52

FIG. 2

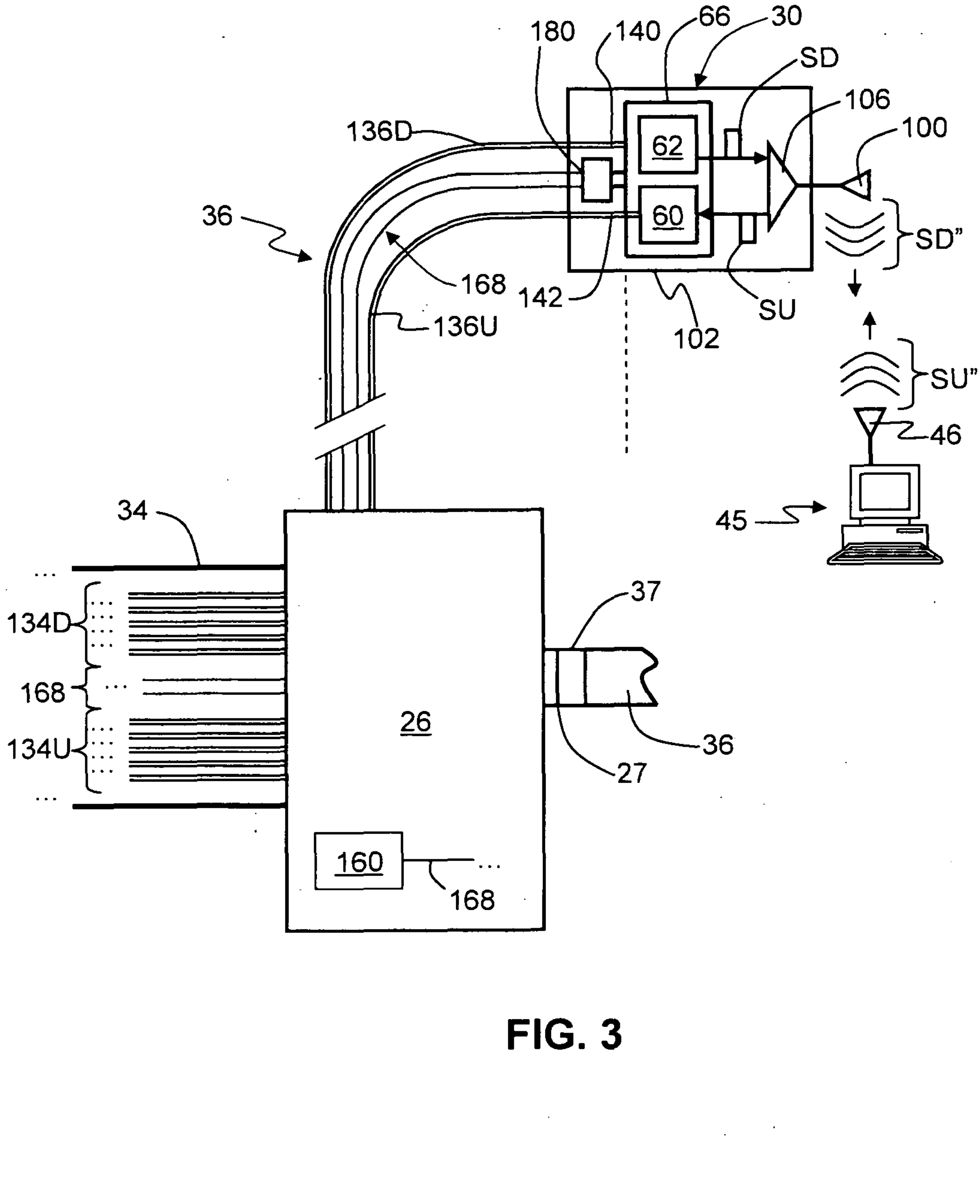
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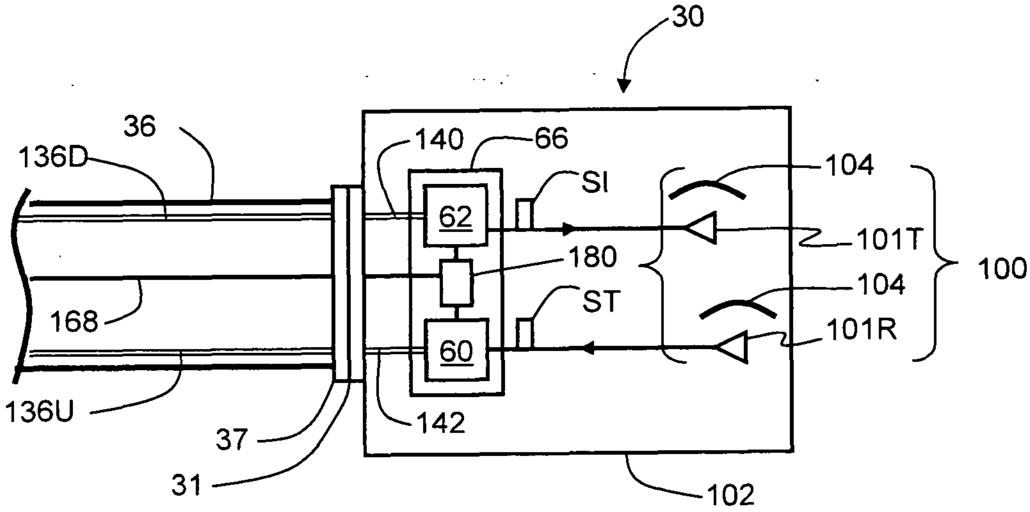
**FIG. 3**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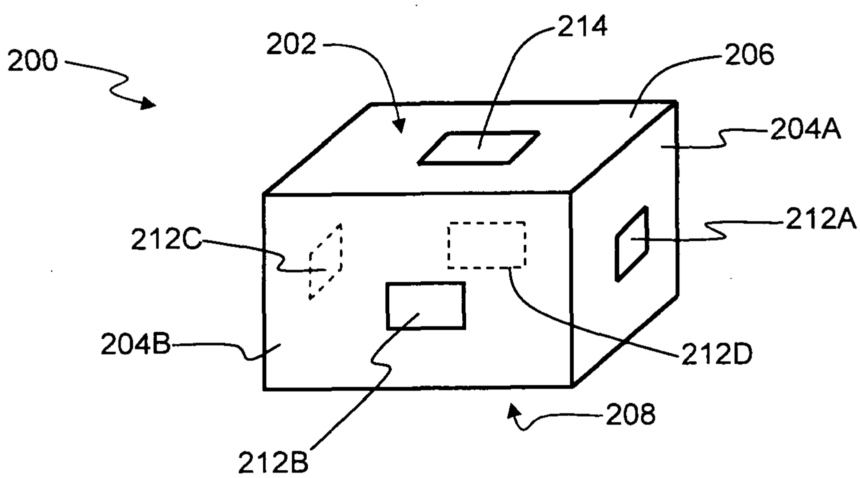
102

FIG. 4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200
204A
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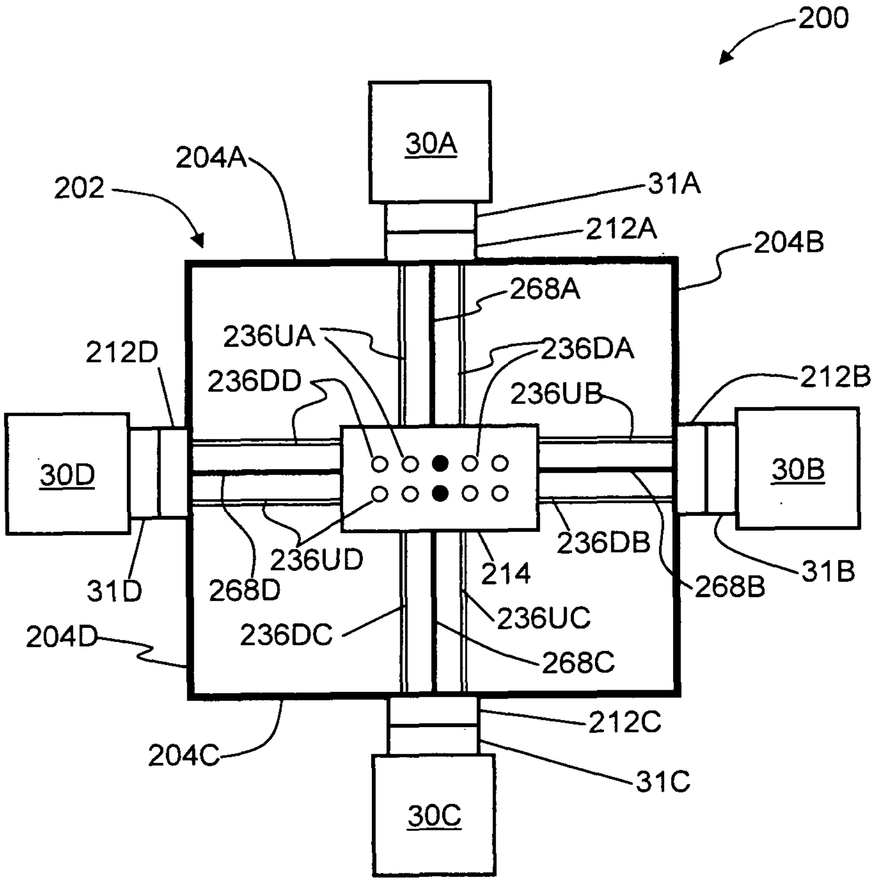
212C
212D
204B
208
212B

FIG. 5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30B
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236DB
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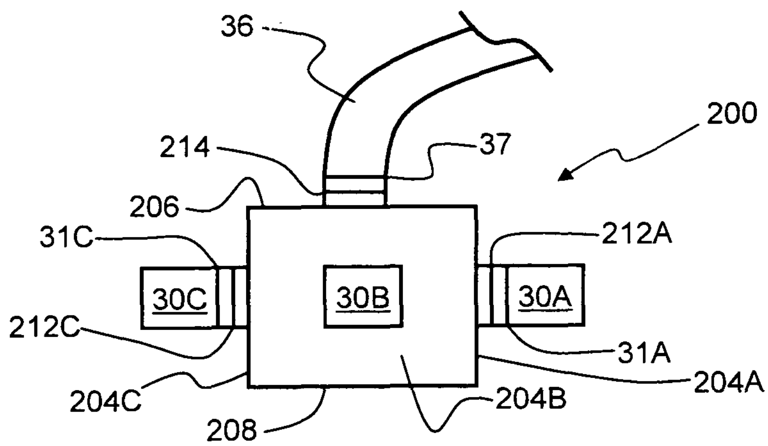
268B
31B
236UC
204D
236DC
268C
212C
204C
31C
30C

FIG. 6


36
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214
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206
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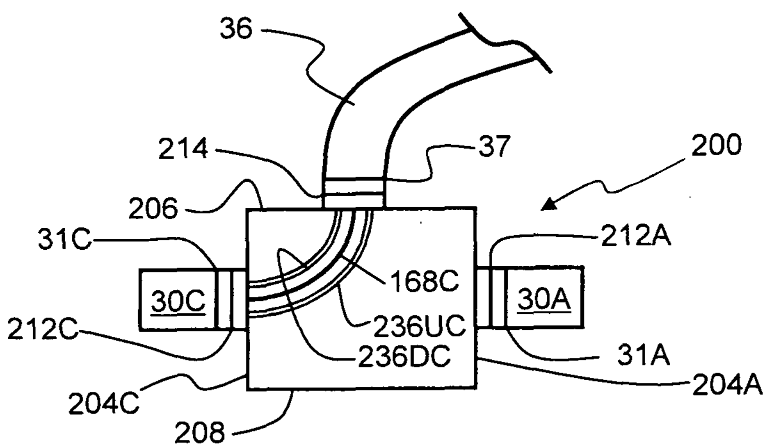
212A
30C
30B
30A
212C
31A
204C
204A
208
204B

FIG. 7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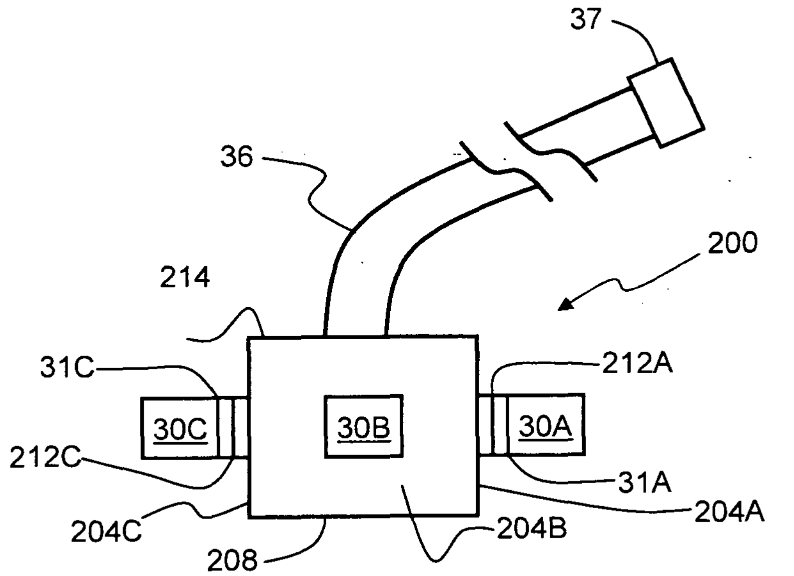
208

FIG. 8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30B
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212C
31A
204C
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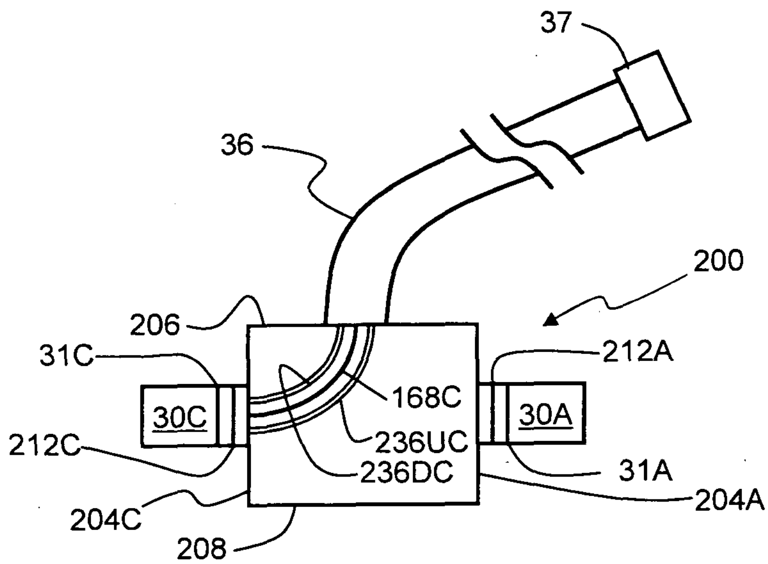
208
204B

**FIG. 9**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36
200
206
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212A
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30C
30A
236UC
212C
236DC
31A
204C
204A
208

**FIG. 10**

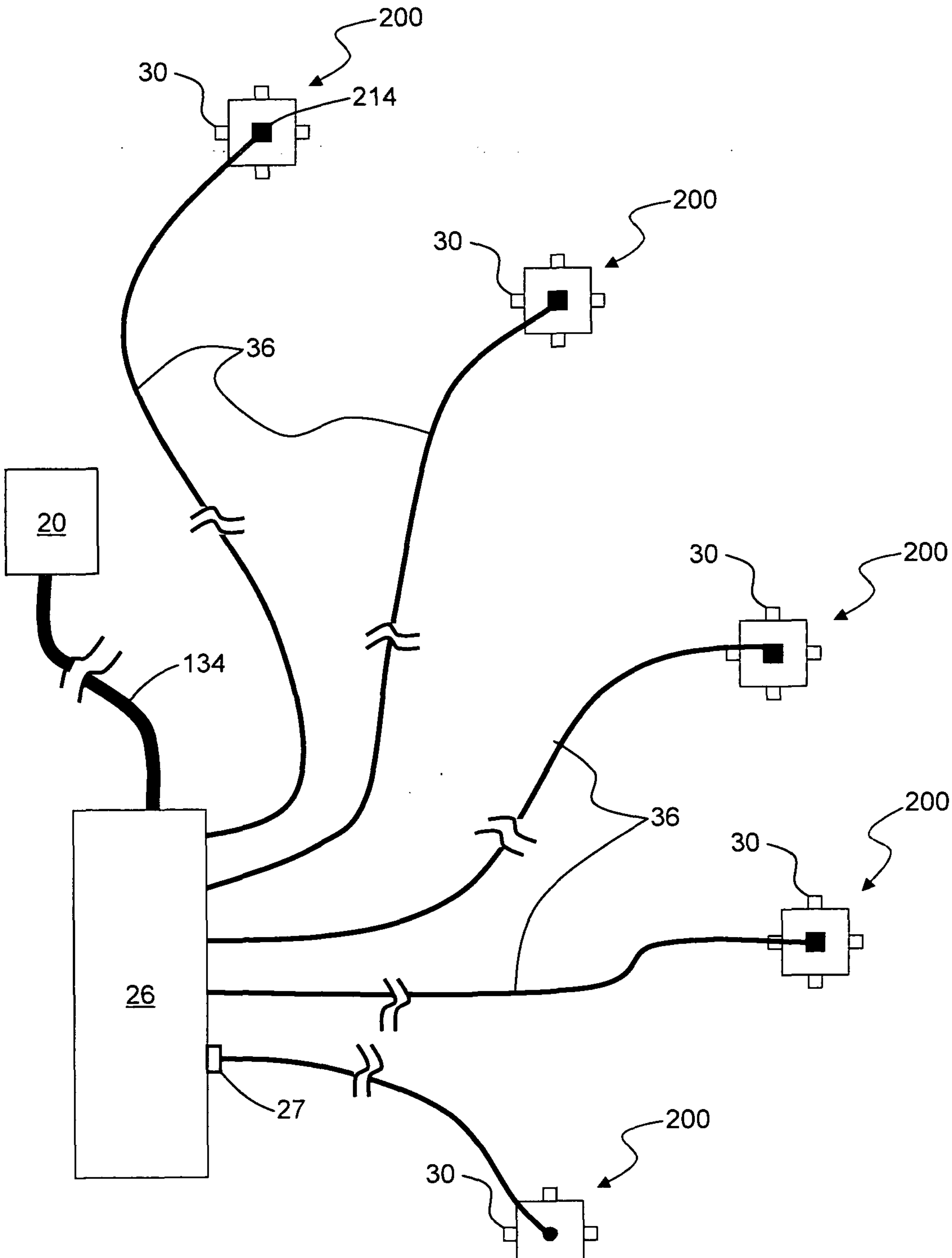



FIG. 11

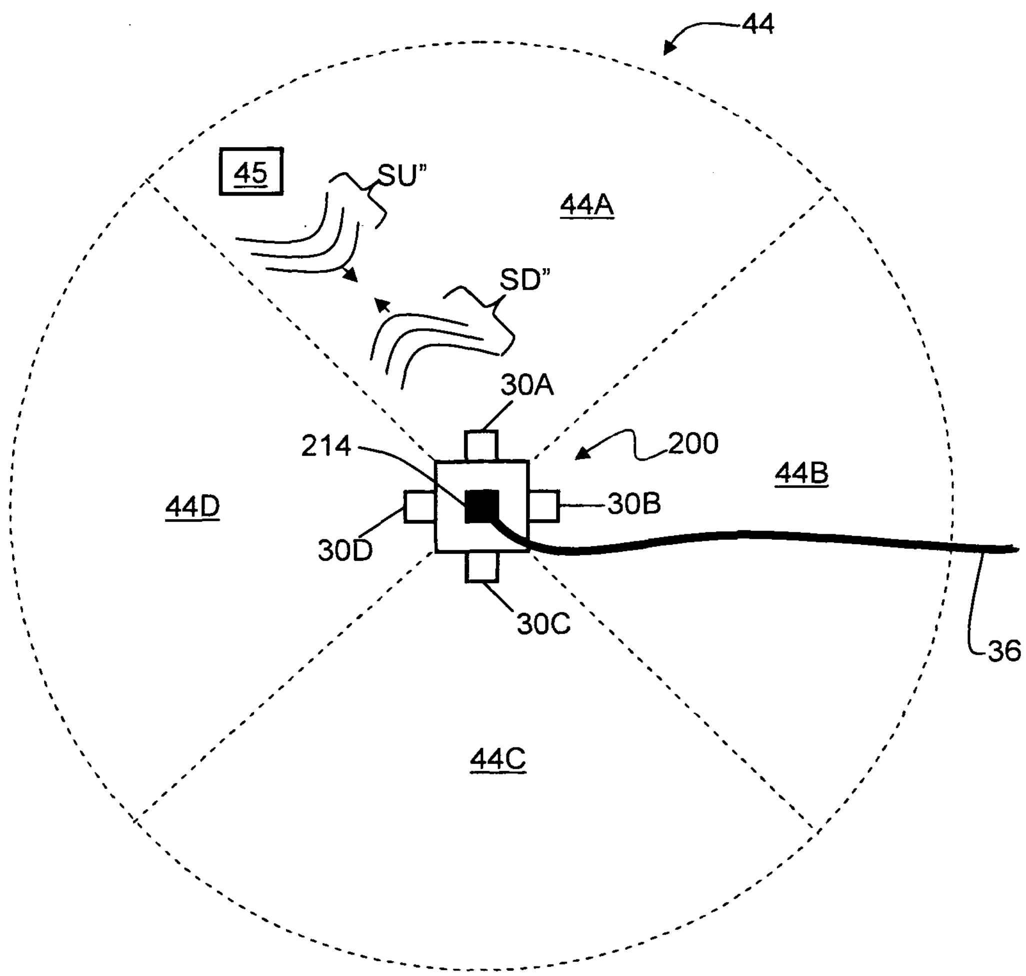
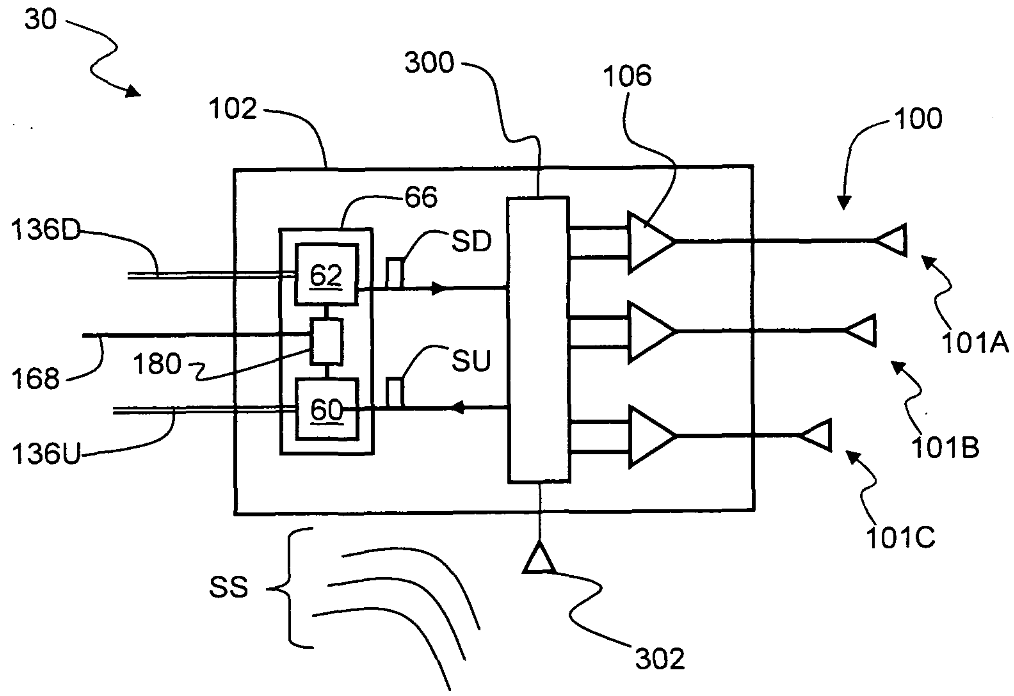



FIG. 12


30
300
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102
100
66
136D
62
SD
168
180
SU
101A
60
136U
101B
101C
SS
302

FIG. 13

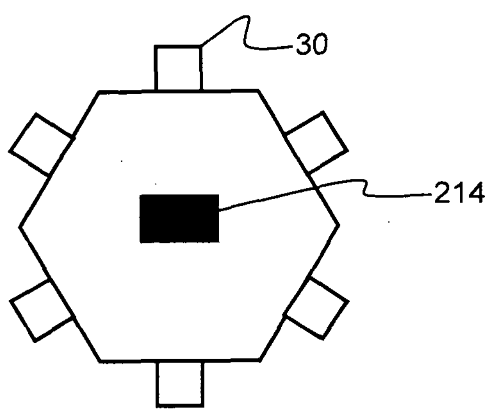
30
214

FIG. 14

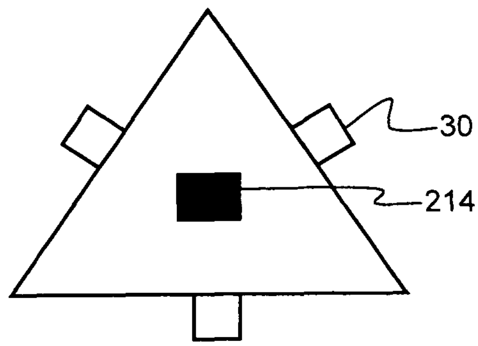


FIG. 15

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2008/008929

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. H04B10/00 H04B10/12 H04B3/44 H04W88/08

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
H04B H04W H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
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| Y | US 5 960 344 A (MAHANY RONALD L [US]) 28 September 1999 (1999-09-28)<br>column 1, line 25 - column 1, line 28<br>column 5, line 16 - column 5, line 30<br>column 7, line 5 - column 7, line 17<br>column 8, line 35 - column 8, line 59; figures 3,6<br>----- | 1-20 |
| A | US 2005/226625 A1 (WAKE DAVID [GB] ET AL) 13 October 2005 (2005-10-13)<br>abstract; figures 1,2<br>----- | 1-20 |
| | -/-- | |

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 4 November 2008 | 11/11/2008 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Phillips, Simon |

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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| A | US 2004/001719 A1 (SASAKI KENSUKE [JP]) 1 January 2004 (2004-01-01) abstract; figure 3 | 1-20 |
| A | EP 1 202 475 A (NTT DOCOMO INC [JP]) 2 May 2002 (2002-05-02) abstract; figure 3 | 1-20 |

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Information on patent family members

International application No
PCT/US2008/008929

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| | | US 2002048071 A1 | 25-04-2002 |