

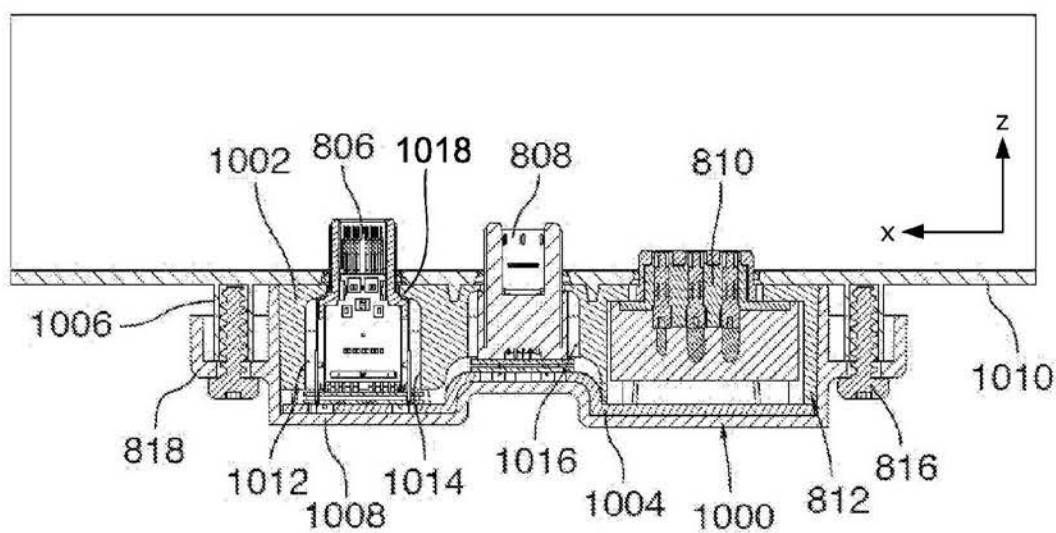


FIG. 10

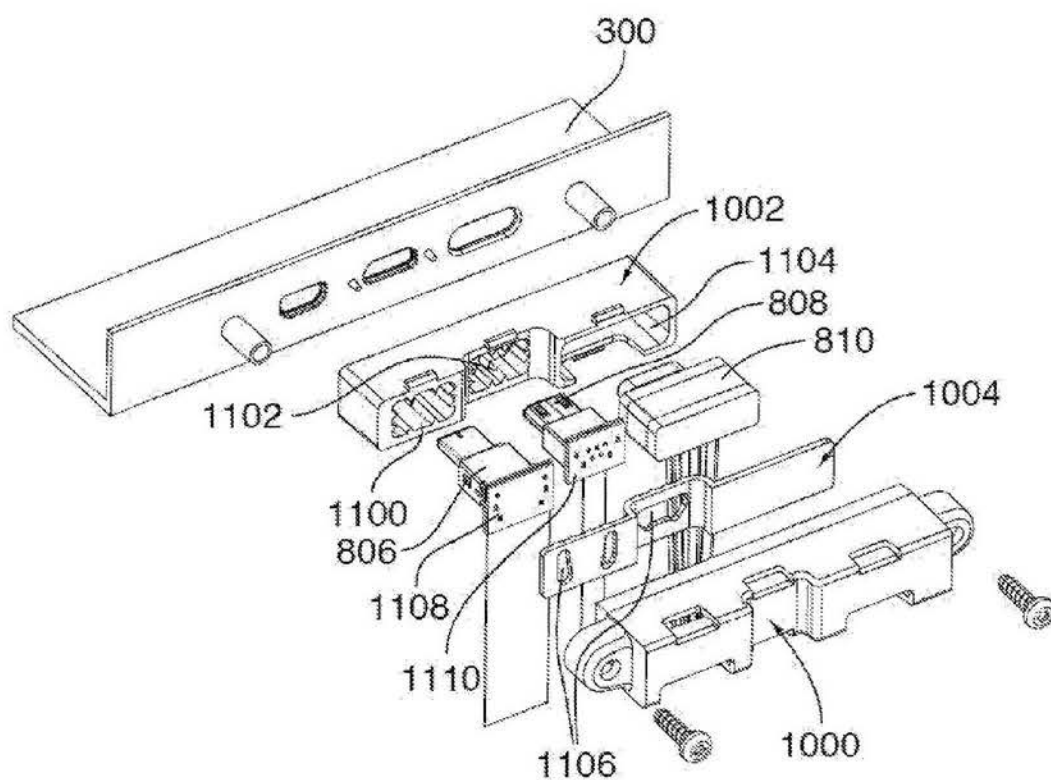


FIG. 11

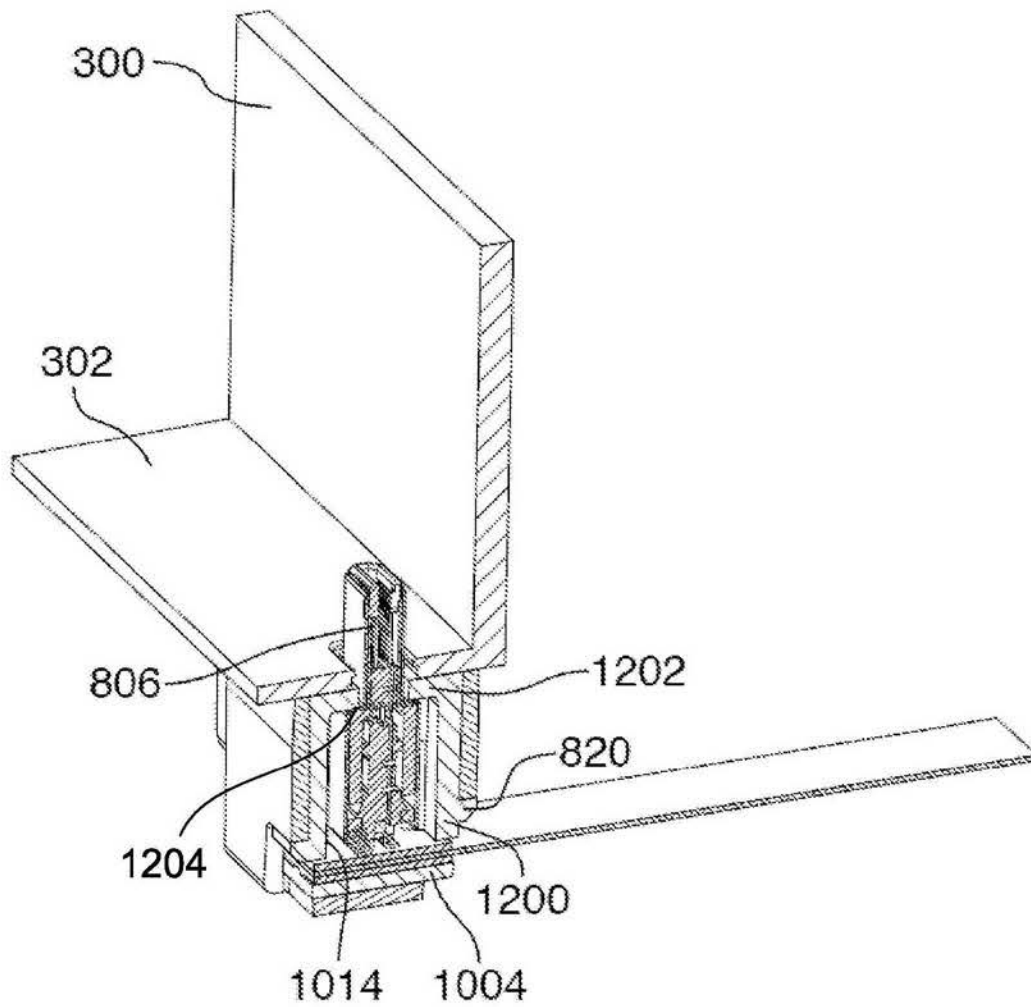


FIG. 12

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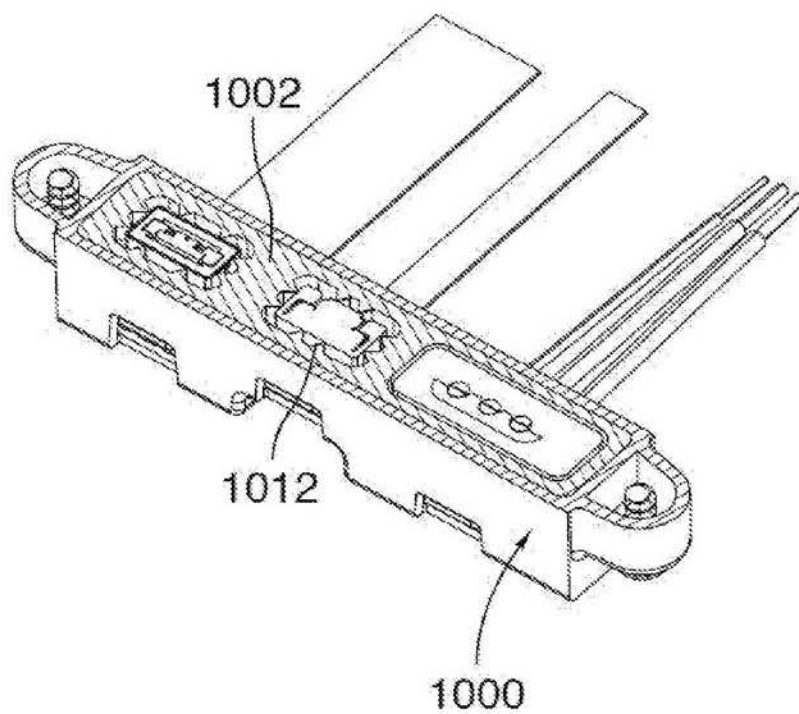


FIG. 13

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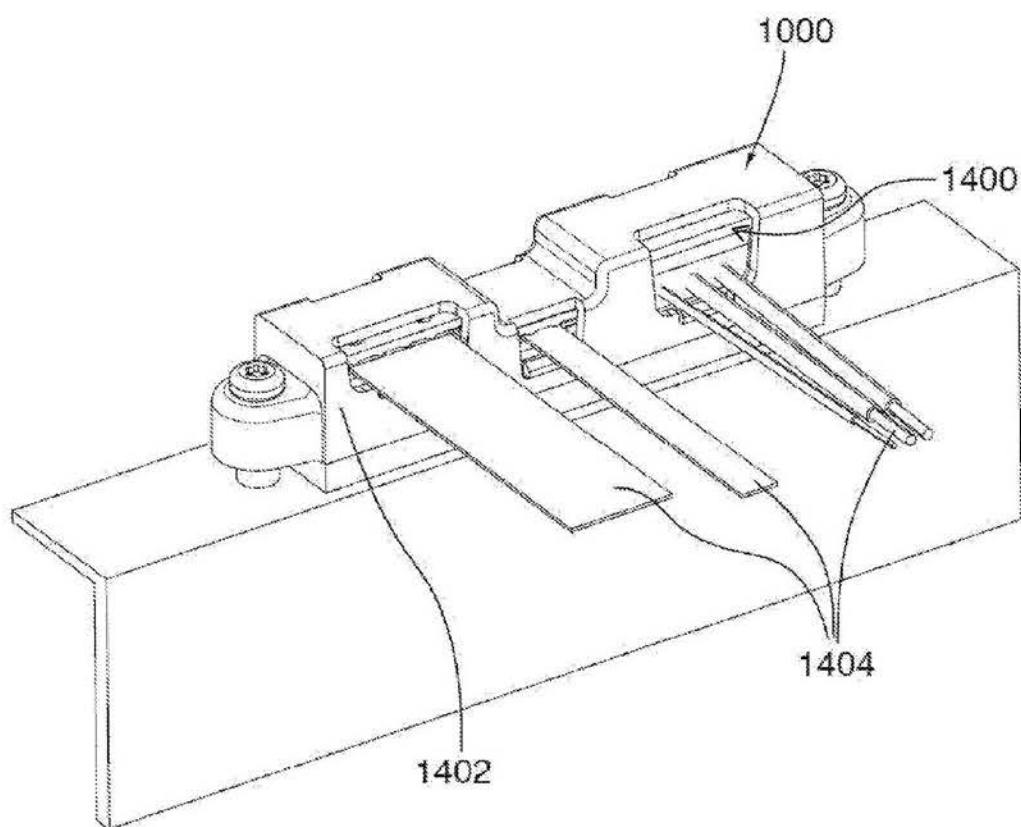


FIG. 14

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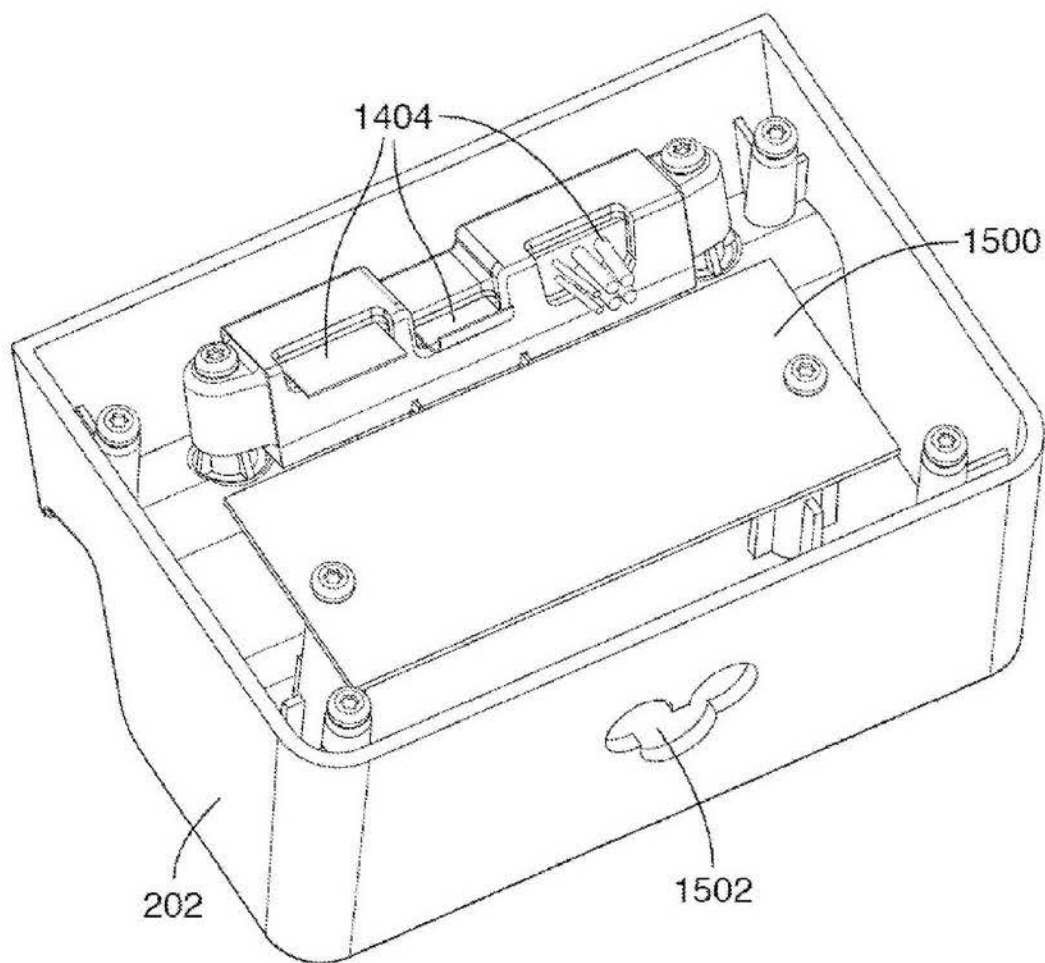


FIG. 15

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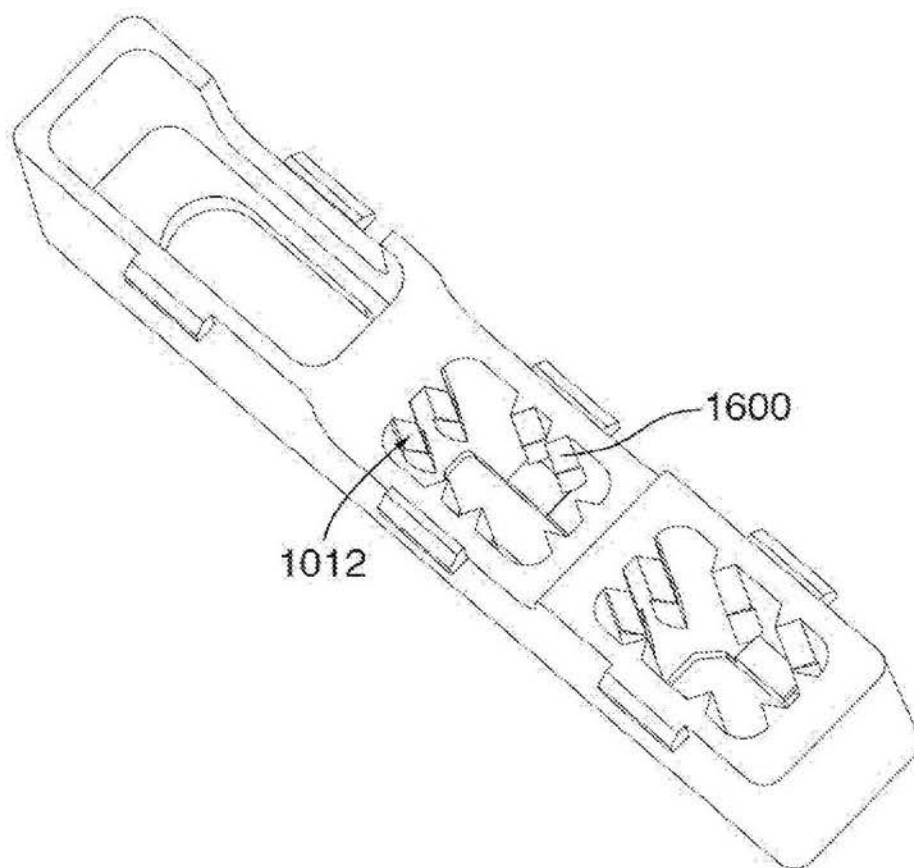


FIG. 16

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**DOCK FOR A PORTABLE ELECTRONIC
DEVICE****CROSS REFERENCE TO RELATED
APPLICATIONS**

The present application claims the benefit of priority of U.S. Provisional Patent Application No. 61/503,451, filed on Jun. 30, 2011, which incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present application relates to charging and/or data transfer docks for portable electronic devices.

BACKGROUND DISCUSSION

Electronic devices, including portable electronic devices, have gained widespread use and may provide a variety of functions including, for example, telephonic, electronic messaging and other personal information manager (PIM) application functions. Portable electronic devices include, for example, several types of mobile stations such as simple cellular telephones, smart telephones, wireless personal digital assistants (PDAs), tablets and laptop computers with wireless 802.11 or Bluetooth capabilities.

Portable electronic devices such as PDAs or smart telephones are generally intended for handheld use (that is, the devices are sized and shaped to be held or carried in a human hand) and ease of portability. Portable electronic devices are often placed in docks for charging or data transfer including transfer of information in any form optically or electrically from dock to portable electronic device and vice versa. Some docks are capable of both charging and data transfer. Docks and portable electronic devices are susceptible to damage due to connection attempts when the portable electronic device and the dock are not properly aligned.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present application will now be described, by way of example only, with reference to the attached Figures, wherein:

FIG. 1 is a simplified block diagram of components including internal components of a portable electronic device;

FIG. 2 is an isometric view of a portable electronic device received in a dock according to an example;

FIG. 3 is a side view of a portable electronic device received in the dock of FIG. 2 with a portion of a housing of the dock removed;

FIG. 4 is a front sectional view of portions of the dock of FIG. 2;

FIG. 5 is a top sectional view on 5-5 of FIG. 4 of portions of the dock of FIG. 2;

FIGS. 6A and 6B are schematic front views of a mating connector of a portable electronic device misaligned with a connector of a dock;

FIG. 7 is a front sectional view of portions of a dock according to another example;

FIG. 8 is an isometric view of a dock according to another example with a charging connector in a stowed position;

FIG. 9 is an isometric view of the dock of FIG. 8 with a charging connector in an extended position;

FIG. 10 is a front sectional view of the dock of FIG. 8;

FIG. 11 is an exploded view of the dock of FIG. 8;

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FIG. 12 is an isometric side sectional view of the dock of FIG. 8;

FIG. 13 is an isometric top sectional view of the dock of FIG. 8;

FIG. 14 is an isometric rear bottom view of the dock of FIG. 8;

FIG. 15 is an isometric view similar to FIG. 14 including additional components of the dock; and

FIG. 16 is an isometric bottom sectional view of a spring component of a dock according to another example.

DETAILED DESCRIPTION

The following describes a dock for receiving a portable electronic device. The dock includes a support for a connector including an elastically deformable portion for allowing movement of the connector relative to the dock when a force is applied.

In an aspect of the present disclosure, there is provided a dock for receiving a portable electronic device, including: a housing comprising an aperture; a support coupled to an inner wall of the housing, a portion of the support being elastically deformable; and a connector received in the support and extending through the aperture for electrically communicating with the portable electronic device, wiring of the connector for transferring data from the portable electronic device; wherein the portion of the support elastically deforms in response to non-axial movement of at least a portion of the connector.

In another aspect of the present disclosure, there is provided a connector assembly for a dock, the connector assembly including: a support for coupling to an inner wall the dock, a portion of the support being elastically deformable; and a connector received in the support and extending through the aperture for electrically communicating with the portable electronic device, wiring of the connector for transferring data from the portable electronic device; wherein the portion of the support elastically deforms in response to non-axial movement of at least a portion of the connector.

For simplicity and clarity of illustration, reference numerals may be repeated among the figures to indicate corresponding or analogous elements. Numerous details are set forth to provide an understanding of the embodiments described herein. The embodiments may be practiced without these details. In other instances, well-known methods, procedures, and components have not been described in detail to avoid obscuring the embodiments described. The description is not to be considered as limited to the scope of the embodiments described herein.

The disclosure generally relates to a dock for a portable electronic device in the embodiments described herein. The dock may receive portable electronic devices including: mobile, or handheld, wireless communication devices such as pagers, cellular phones, cellular smart-phones, wireless organizers, tablets, global positioning system devices and personal digital assistants, for example. The portable electronic device may also be a portable electronic device without wireless communication capabilities, such as a handheld electronic game device, digital photograph album, digital camera, or other device. The portable electronic device may be, but need not be, a handheld device.

A block diagram of an example of a portable electronic device 100 is shown in FIG. 1. The portable electronic device 100 includes multiple components, such as a processor 102 that controls the overall operation of the portable electronic device 100. Communication functions, including data and voice communications, are performed through a communica-

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tion subsystem 104. Data received by the portable electronic device 100 is decompressed and decrypted by a decoder 106. The communication subsystem 104 receives messages from and sends messages to a wireless network 120. The wireless network 120 may be any type of wireless network, including, but not limited to, data wireless networks, voice wireless networks, and networks that support both voice and data communications.

A power pack 122, such as one or more rechargeable batteries or a port to an external power supply, powers the portable electronic device 100. A dock interface 140 may electrically communicate with a dock 150 to charge the power pack 122 and/or provide a data connection to a data port 126 of the portable electronic device 100. In general, components electrically communicate with one another when the electrical activity in one component affects an electrical activity in another. Electrical communication includes direct electrical contact that enables current flow. The dock interface 140 may include one or more mating connectors for electrically communicating with connectors of the dock 150. The dock 150 may electrically communicate with one or more of a power source 142, multimedia devices 144 such as televisions, monitors, projectors or other output devices, for example, and other electronic devices 146. In some situations, communication may be electrical or optical or a combination of electrical and optical.

The processor 102 interacts with other components, such as Random Access Memory (RAM) 108, memory 110, a display 112, an input device 114, an auxiliary input/output (I/O) subsystem 124, a data port 126, a speaker 128, a microphone 130, short-range communications 132, and other device subsystems 134. The processor 102 may interact with an orientation sensor such as an accelerometer 136 that may be utilized to detect direction of gravitational forces or gravity-induced reaction forces.

To identify a subscriber for network access, the portable electronic device 100 uses a Subscriber Identity Module or a Removable User Identity Module (SIM/RUIM) card 138 for communication with a network, such as the wireless network 120. Alternatively, user identification information may be programmed into memory 110.

The portable electronic device 100 includes an operating system 116 and software programs or components 118 that are executed by the processor 102 and are typically stored in a persistent, updatable store such as the memory 110. Additional applications or programs may be loaded onto the portable electronic device 100 through the wireless network 120, the auxiliary I/O subsystem 124, the data port 126, the short-range communications subsystem 132, or any other suitable subsystem 134.

A received signal such as a text message, an e-mail message, or web page download is processed by the communication subsystem 104 and input to the processor 102. The processor 102 processes the received signal for output to the display 112 and/or to the auxiliary I/O subsystem 124. A subscriber may generate data items, for example e-mail messages, which may be transmitted over the wireless network 120 through the communication subsystem 104. For voice communications, the overall operation of the portable electronic device 100 is similar. The speaker 128 outputs audible information converted from electrical signals, and the microphone 130 converts audible information into electrical signals for processing.

An example dock 150 for receiving a portable electronic device 100 is shown in FIGS. 2 and 3. The dock 150 includes a housing 200 that is shaped to receive the portable electronic device 100. In one example, the housing 200 includes a seat

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302 and a support wall 300 for receiving the portable electronic device 100. In general, the support wall 300 and the seat 302 support the weight of a received portable electronic device 100, although in some of the embodiments depicted herein, the seat 302 may support more weight than the support wall 300. As shown in FIG. 3, an edge surface 304 of the portable electronic device 100 contacts the seat 302 of the housing 200 and a rear surface 306 of the portable electronic device 100 contacts the support wall 300 of the housing 200. The size and shape of the seat 302 and the support wall 300 and the angle between the seat 302 and the support wall 300 may be selected to accommodate different sizes and types of portable electronic devices 100.

The housing 200 may be molded plastic, machined metal or wood, for example. The housing may be a single part or may be an assembly of multiple parts.

The dock 150 includes a connector support assembly 308 that is coupled to an inner surface of the housing 200. In general, components are coupled to one another when movement of one component affects movement in the other component. Coupling may be permanent, such as by welding for example, or may be reversible, such as connection by fasteners, for example. Coupling may include direct contact between the two components or the components may be spaced from one another with additional components being provided to achieve coupling between the two components. In one example, screws 310 couple lugs 312 of the support assembly 308 to screw-receiving components 314, which extend from an underside surface 316 of the seat 302, to couple the support assembly 308 to the housing 200.

Referring also to FIG. 4, the connector support assembly 308 receives a connector 400. The connector 400 may be a charging connector, a data connector or a connector capable of both charging and data transfer. The connector 400 may support an electrical connection, an optical connection or a combination thereof. A connecting portion of the connector 400 extends through an aperture 402, which is located in the seat 302. When the portable electronic device 100 is received in the dock 150, the connector 400 electrically or optically communicates with the portable electronic device 100 to charge the portable electronic device 100 and/or provide a data connection thereto. In general, the portable electronic device 100 is received in the dock 150 when the portable electronic device 100 is generally supported thereby. Similarly, a first component may be received in a second component when the first component is supported by the second component. The first component may or may not be coupled to the second component and may move relative to the second component.

The connector support assembly 308 includes a support 404, a spring component 406, which is received in the support 404, and a flexible pad 412, which is located on a base 408 of the support 404. The base 408 of the support 404 limits movement of the connector 400 in a z-direction to facilitate coupling with a mating connector of the portable electronic device 100. An opening (not shown) is provided in the support 404 to allow wiring (such as electrical conductors or optical cables, not shown) of the connector 400 to pass therethrough.

The spring component 406 includes a passage 500, which is shown in FIG. 5, for receiving the connector 400. The passage 500 extends between a top end 414 of the spring component 406 and a bottom end 416 of the spring component 406. A collar 418 is located at the top end 414 of the spring component 406 and ribs 410 extend from an inner wall 502 of the passage 500. The collar 418 includes a contact surface 420, which abuts the connector 400 to limit transla-

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tion of the connector 400 in the x and y directions. The collar 418 may fully or partially surround the connector 400.

The ribs 410 extend vertically relative to the passage 500 and are elastically deformable to accommodate movement of the connector 400. The ribs 410 contact the connector 400 in order to maintain the connector 400 in a starting position within the passage 500. The spring component 406 is biased toward the starting position, which is a non-deformed shape shown in FIG. 5. Any non-axial movement of the connector 400 may cause the ribs 410 of the spring component 406 to elastically deform. An amount of movement of the connector 400 relative to the connector support assembly 308 may be determined by one of both of a rigidity of the ribs 410 and a size of the aperture 402.

The pad 412 is elastically deformable to accommodate some movement of the connector 400 in the z direction. Movement may occur in response to a force applied in the z-axis or pivoting of the connector 400. The pad 412 may be interference fit with the connector 400 to bias the connector 400 toward the mating connector of the portable electronic device 100 and absorb tolerances. The pad 412 is biased toward a non-deformed shape, as shown in FIG. 4.

The spring component 406 is made from a flexible material such as silicone rubber, urethane rubber or cork, for example. A hard plastic having flexible fingers may alternatively be used. The spring component 406 may fully surround the connector 400, as shown in FIG. 5, or may partially surround the connector 400. The spring component 406 may include a different number of ribs than shown in the figures. Further, the spring component may be any spring component that allows movement of the connector 400 relative to the connector support assembly 308 and biases the connector 400 to the starting position within aperture 402.

In operation, a user visually and/or tactilely aligns a mating connector of the portable electronic device 100 with the connector 400 of the dock 150 and then moves the mating connector into engagement with the connector 400. When the mating connector is misaligned with the connector 400 in the x and/or y directions, a force is imparted on the connector 400 by the portable electronic device 100. The ribs 410 of the spring component 406 and the pad 412 elastically deform in order to accommodate pivoting of the connector 400 in response to the force. An example of a pivoted position of the connector 400 is shown in dashed lines in FIG. 4. Multiple forces may be applied to the connector 400 in various different directions while the user attempts to join the connectors of the portable electronic device 100 and dock 150. Because the example dock 150 of FIG. 2 includes a single connector 400, the ribs 410 of the spring component 406 return the connector 400 and the portable electronic device 100 back to the starting position once the connection with the portable electronic device 100 is complete. For heavy portable electronic devices 100, the ribs 410 may remain in a deformed position until the portable electronic device 100 is removed from the dock 150.

Two examples of misalignment between mating connector of the portable electronic device 100 and the connector 400 are shown in FIGS. 6A and 6B. The dock 150 described herein generally avoids damage to the connector 400 because the force imparted by the mating connector of the portable electronic device 100 is absorbed by the spring component 406 rather than the connector 400.

The connector support assembly 308 may be any support that is coupled to the housing 200 and includes a portion that elastically deforms in response to movement of the connector 400. In addition, an alignment component may be provided to facilitate location of the mating connector of the portable electronic device 100 relative to the connector 400. The align-

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ment component may be a rail, pin or slot, for example, for guiding the portable electronic device 100 into position.

In another example, ribs 710, which are shown in FIG. 7, extend generally horizontally in the spring component 406. The orientation of the ribs may alternatively be disposed at an angle that is between vertical and horizontal.

In another example, the connector extends through an aperture in the support wall or other location in order to accommodate different locations of portable electronic device mating connectors.

Although the collar 418 is shown as part of the spring component 406, the collar 418 may alternatively form part of the seat 302. In another example, the spring component 406 does not include a collar 418. In this embodiment, both translation in the x and y directions and pivoting of the connector 400 relative to the housing 200 are possible.

Referring now to FIGS. 8 and 9, another example of a dock 150 for a portable electronic device 100 is generally shown. In this example, the dock 150 includes apertures 800, 802, 804, which extend through the seat 302 of the housing 200. First and second data connectors 806 and 808 extend through apertures 800 and 802, respectively. A charging connector 810 extends through the aperture 804. When the portable electronic device 100 is received in the dock 150, the connectors 806, 808, 810 electrically communicate with the portable electronic device 100 to provide data connections and charge the portable electronic device 100. In one example, the first data connector 806 is a micro HDMI connector for transferring data to multimedia devices and the second data connector 808 is a micro USB connector for exchanging data with other electronic devices. Other types of data connectors are also possible. In addition, the charging connector 810 may also transfer data.

The connectors 806, 808, 810 are mounted in a connector support assembly 812, which is coupled to an inner surface of the housing 200. Referring also to FIG. 10, screws 816 couple lugs 818 of the support assembly 812 to screw-receiving components 1006, which extend from an underside surface 1010 of the seat 302, to couple the support assembly 812 to the housing 200. Other arrangements for coupling the connector support assembly to the housing 200 are also possible.

Referring still to FIGS. 8, 9 and 10, the connector support assembly 812 includes a support tray 1000, a spring component 1002, which is located in the support tray 1000, and a pad 1004, which is disposed between a base 1008 of the support tray 1000 and the spring component 1002. The spring component 1002 includes tabs 820, which mate with openings 822 in a front wall 824 of the support tray 1000 to generally fix the spring component 1002 relative to the support tray 1000. Alternative arrangements for fixing the spring component 1002 in the support tray 1000 are possible including fasteners, such as screws, rivets or staples, glue, or other snap-in fastening arrangements. In addition, the spring component 1002 may be sized so that an interference fit is provided between the spring component 1002 and the connectors 806, 808.

The spring component 1002 includes passages 1100, 1102 and 1104, which are shown in FIG. 11. The passages 1100, 1102, 1104 extend between a bottom end 1200 of the spring component 1002 to a top end 1202. The passages 1100, 1102 and 1104 receive first and second data connectors 806, 808 and charging connector 810, respectively. The charging connector 810 is movable in the z direction through the passage 1104 between a stowed position, which is shown in FIG. 8, and an extended position, which is shown in FIG. 9. The charging connector 810 is generally a floating connector that is biased toward the stowed position and moveable under a magnetic force to the extended position. Passage 1104, which

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receives the charging connector **810** and allows the charging connector **810** to slide relative thereto.

Collars **1018** are located at the top end **1202** of the spring component **1002** to surround the passages **1100**, **1102** and ribs **1012** extend from inner walls **1014** of the passages **1100**, **1102**. Contact surfaces **1204** of the collars **1018** abut the connectors **806**, **808** to limit translation of the connectors **806**, **808** in the x and y directions. The collars **1018** may fully or partially surround the connectors **806**, **808**.

Ribs **1012** extend from inner walls **1014** and **1016** of passages **1100** and **1102** of the spring component **1002**, respectively. The ribs **1012** contact the first and second data connectors **806**, **808** in order to maintain the connectors **806**, **808** in a starting position within the respective passages **1100**, **1102**. The spring component **1002** is biased toward a non-deformed shape, which is shown in FIG. 13, or a slightly deformed state in which some deformation may occur in response to interference with the connectors **806**, **808**. An amount of movement of the connectors **806**, **808** relative to the connector support assembly **812** may be determined by one of both of a rigidity of the spring component **1002** and a size of the apertures **800** and **802**, respectively. The spring component **1002** facilitates independent movement of the connectors **806**, **808**, **810**. Elastic deformation due to a force being applied to one of the connectors is not transferred to the other connectors through the spring component **1002**.

The spring component **406** is made from a flexible material such as silicone rubber, urethane rubber or cork, for example. A hard plastic having flexible fingers may alternatively be used.

Because the mating connectors of the portable electronic device **100** are fixed relative to one another, additive tolerances may result in displacements in mating connector locations when compared to manufacturing specifications of the portable electronic device **100**. Additive tolerances are generally the sum of internal tolerances of each mating connector component, tolerances of components coupled the mating connector components and assembly process tolerances. The connector support assembly **812** compensates for the additive tolerances of the mating connectors of the portable electronic device **100** by providing a spring component **1002** that allows connectors **806**, **808** of the dock **150** to pivot in order to align with the mating connectors of the portable electronic device **100**. Because the connectors **806**, **808** are not fixed relative to the dock **150**, manufacturing of the dock **150** may be simplified because tolerances relating to connector location within the dock **150** may be relaxed compared to fixed connector docks.

The base **1008** of the support tray **1000** limits movement of the connectors **806**, **808** in the z-direction to facilitate coupling with mating connectors of the portable electronic device **100**. The pad **1004** is elastically deformable to accommodate some movement of the connectors **806** and **808** in the z direction. The pad **1004** may be interference fit with the connectors **806**, **808** to bias the connectors **806**, **808** toward the mating connectors of the portable electronic device **100** and absorb tolerances. The pad **1004** is biased toward a non-deformed shape, which is shown in FIG. 10, and is compressible in response to a downward, or axial, force on the connector **806**, **808**. In one example, the pad **804** is two-shot or overmolded onto the support tray **1000** to reduce the part count of the dock **150**.

As shown in FIG. 11, apertures **1106** extend through the pad **1004**. Referring also to FIG. 10, the apertures **1106** are aligned with the through-hole leads of the connectors **806**, **808**, which protrude through an opposite surface of printed circuit boards (PCB), **1108**, **1110** of the first and second data

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connectors **806**, **808**, respectively. The apertures **1106** generally protect the leads and solder joints of the PCB **1108**, **1110** from stress during assembly and use when the portable electronic device **100** is inserted into and removed from the dock **150**.

Referring also to FIG. 14, the support tray **1000** includes openings **1400**, which extend through a rear wall **1402** of the support tray **1000** to allow wiring **1404** of the connectors **806**, **808**, **810** to extend therethrough. The wiring **1404** may be flexible cables coupled between the connectors **606**, **608**, **610** and an electronic device (not shown), a multimedia device (not shown) and a power source (not shown), respectively. In one example, the flexible cables are coupled to a connector (not shown) that is mounted on a main PCB **1500** coupled inside the housing **200**, as shown in FIG. 15. The flexible cables may alternatively be soldered to the main PCB **1500**. When a main PCB is not included, the flexible cables may be soldered, crimped or inserted into mating pins of one or more connectors. Cables for electrically communicating with the electronic device, multimedia device and power source may extend through opening **1502**.

In operation, a user visually and/or tactilely aligns mating connectors of the portable electronic device **100** with the connectors **806**, **808** and **810** of the dock **150** and then moves the mating connectors into engagement with the connectors **806**, **808**, **810**. When the mating connectors are not aligned with the connectors **806**, **808** in the x and/or y directions, a force is imparted on one or both of the connectors **806**, **808** by the portable electronic device **100**. The ribs **1012** of the spring component **1002** and the pad **1004** elastically deform in order to accommodate pivoting of the one or both of the connectors **806**, **808** in response to the force. Multiple forces may be applied to the connectors **806**, **808** in various different directions while the user attempts to join the connectors of the portable electronic device **100** and dock **150**. The charging connector **810** moves toward the mating charging connector of the portable electronic device **100** when the magnet of the mating charging connector is near the charging connector **810**. Once connected, the connectors **806**, **808** may return to their starting positions or one or both of the connectors **806**, **808** may remain out of alignment with the starting position due to additive tolerances of the mating connectors of the portable electronic device **100**. Because the connectors **806**, **808** are able to pivot in order to align with the mating connectors, additive tolerance issues relating to more than one fixed mating connector are avoided.

Referring to FIG. 16, in another example, the ribs **1012** include steps **1600**. Two or more steps **1600** are spaced along the length of the ribs **1012** to decrease a rib cross-sectional area between the top end **1202** and a bottom end **1200** of the spring component **1002**. When a mating connector of a portable electronic device **100** exerts a force on the connector **806**, **808**, in the x and/or y direction, a maximum compressive force is applied near the top end **1202** of the spring component **1002**. By providing a larger rib cross-sectional area near the top end **1202**, the amount of force that is transferred to the bottom end **1200** of the spring component **1002** is reduced. Therefore, damage to solder joints, for example, between the PCBs **1108**, **1110** and the connectors **806**, **808**, respectively, is less likely to occur. Similarly, stress resulting from any shifting, tilting or other alignment forces exerted by the mating connectors of the portable electronic device **100** is reduced.

The charging connector **810** may be replaced with a fixed connector that is mounted within the connector support assembly **812** in a similar manner as data connectors **806** and

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808. Further, although three connectors are shown in the example of FIGS. 9 to 15, any number of connectors may be possible.

The connector support assembly and connector(s) may be provided as a single connector assembly that may be mounted in any dock. The connector support assembly may be manufactured to meet specifications associated with docks of different portable electronic devices.

Although the collar 1018 is shown as part of the spring component 1002, the collar 1018 may alternatively form part of the seat 302. In another example, the spring component 1002 does not include a collar 1018. In this example, both translation in the x and y directions and pivoting of the connectors 806, 808 relative to the housing 200 are possible.

The dock 150 described herein may realize one or more advantages, some of which have already been described. The dock 150 facilitates quick and easy connection of a portable electronic device thereto. By compensating for some misalignment between connectors of the dock 150 and mating connectors of the portable electronic device, damage resulting from stress on both the portable electronic device 100 and the dock 150 normally associated with connection and removal operations, may be avoided. Further, the life of the dock 150 may be extended because entry of dust and dirt into the dock 150 is limited by the collar, which may act as a seal.

The above-described embodiments are intended to be examples only. Alterations, modifications and variations can be effected to the particular embodiments by those of skill in the art without departing from the scope of the present application, which is defined solely by the claims appended hereto.

What is claimed is:

1. A dock for receiving a portable electronic device, comprising:

a housing comprising an aperture;

a support coupled to an inner wall of the housing, a portion of the support being elastically deformable;

a connector received in the support and extending through the aperture for electrically communicating with the portable electronic device, wiring of the connector for transferring data from the portable electronic device; and

a collar abutting the connector within the housing to limit translation of the connector, the connector being pivotable relative to the collar;

wherein the portion of the support elastically deforms in response to non-axial movement of at least a portion of the connector.

2. A dock as claimed in claim 1, wherein the support includes a spring component received in a support tray, the spring component being elastically deformable.

3. A dock as claimed in claim 2, wherein the spring component comprises a passage for receiving the connector, the passage comprising ribs for contacting the connector.

4. A dock as claimed in claim 2, wherein the spring component biases the connector to a starting position within the passage.

5. A dock as claimed in claim 2, wherein the spring component comprises three passages for receiving a first data connector, a second data connector and a charging connector.

6. A dock as claimed in claim 1, wherein the collar surrounds the connector at a location adjacent the aperture.

7. A dock as claimed in claim 1, comprising more than one connector, each connector being independently movable relative to the housing.

8. A dock as claimed in claim 1, wherein the housing comprises a seat for receiving the portable electronic device and the aperture extends through the seat.

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9. A dock as claimed in claim 1, wherein the connector is a micro HDMI connector.

10. A dock as claimed in claim 1, wherein the connector is a micro USB connector and the wiring receives data from an electronic device.

11. A dock as claimed in claim 1, wherein the connector is a charging connector.

12. A dock for receiving a portable electronic device, comprising:

a housing comprising an aperture;

a support coupled to an inner wall of the housing, the support comprising a spring component received in a support tray, the spring component comprising a passage for receiving the connector, the passage comprising ribs for contacting the connector, the spring component being elastically deformable in response to non-axial movement of at least a portion of the connector; and

a connector received in the support and extending through the aperture for electrically communicating with the portable electronic device, wiring of the connector for transferring data from the portable electronic device; wherein a cross-sectional area of the ribs is reduced between a top end of the spring component and a bottom end of the spring component, the top end being located adjacent the aperture of the housing.

13. A dock for receiving a portable electronic device, comprising:

a housing comprising an aperture;

a support coupled to an inner wall of the housing, a portion of the support being elastically deformable;

a pad disposed in the support and elastically deformable in response to axial movement of the connector; and

a connector received in the support and extending through the aperture for electrically communicating with the portable electronic device, wiring of the connector for transferring data from the portable electronic device; wherein the portion of the support elastically deforms in response to non-axial movement of at least a portion of the connector.

14. A connector assembly for a dock, the connector assembly comprising:

a support for coupling to an inner wall the dock, the support comprising a spring component received in a support tray, the spring component comprising a passage, the spring component being elastically deformable; and

a connector received in the support and extending through the passage for electrically communicating with a portable electronic device received by the dock, wiring of the connector for transferring data from the portable electronic device;

wherein the passage comprises ribs for contacting the connector and a cross-sectional area of the ribs is reduced between a top end of the spring component and a bottom end of the spring component, the top end being located adjacent the aperture of the housing.

15. A connector assembly for a dock, the connector assembly comprising:

a support for coupling to an inner wall the dock, the support comprising a collar, a portion of the support being elastically deformable; and

a connector received in the support for electrically communicating with a portable electronic device received by the dock, wiring of the connector for transferring data from the portable electronic device;

wherein the portion of the support elastically deforms in response to non-axial translation and pivoting relative to the collar of at least a portion of the connector.

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16. A connector assembly as claimed in claim 15, wherein the support includes a spring component received in a support tray, the spring component being elastically deformable.

17. A connector assembly as claimed in claim 16, wherein the spring component comprises a passage for receiving the connector, the passage comprising ribs for contacting the connector. 5

18. A connector assembly as claimed in claim 15, wherein the spring component biases the connector to a starting position within the passage. 10

19. A connector assembly as claimed in claim 15, comprising a collar abutting the connector within the housing to limit translation of the connector.

* * * * *

12

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 8,545,247 B2
APPLICATION NO. : 13/397486
DATED : October 1, 2013
INVENTOR(S) : Leonardo Aldana et al.

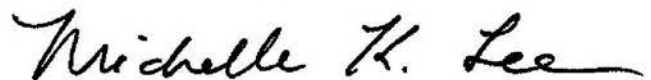
Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims:

Column 9, line 54, claim 4, delete "claim 2" and insert therefor -- claim 3 --.

Signed and Sealed this
Third Day of June, 2014



Michelle K. Lee
Deputy Director of the United States Patent and Trademark Office

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 8,545,247 B2
APPLICATION NO. : 13/397486
DATED : October 1, 2013
INVENTOR(S) : Leonardo Aldana et al.

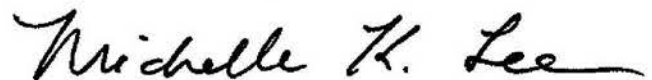
Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims:

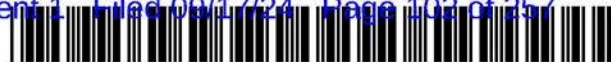
Column 11, line 8, claim 18, delete "claim 15" and insert therefor -- claim 17 --

Signed and Sealed this
Twelfth Day of August, 2014



Michelle K. Lee
Deputy Director of the United States Patent and Trademark Office

EXHIBIT E



US007529305B1

(12) **United States Patent**
Tong et al.

(10) **Patent No.:** **US 7,529,305 B1**

(45) **Date of Patent:** **May 5, 2009**

(54) **COMBINATION OF SPACE-TIME CODING AND SPATIAL MULTIPLEXING, AND THE USE OF ORTHOGONAL TRANSFORMATION IN SPACE-TIME CODING**

(75) Inventors: **Wen Tong**, Ottawa (CA); **Michail G. Bakulin**, Kirova (RU); **Vitaly B. Kreyndelin**, Moscow (RU); **Alexander M. Shloma**, Gagarina (RU); **Yuriy S. Shinakov**, Moscow (RU)

(73) Assignee: **Nortel Networks Limited**, St. Laurent, Quebec (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 887 days.

(21) Appl. No.: **10/399,859**

(22) PCT Filed: **Oct. 27, 2000**

(86) PCT No.: **PCT/RU00/00426**

§ 371 (c)(1),
(2), (4) Date: **Aug. 29, 2003**

(87) PCT Pub. No.: **WO02/35762**

PCT Pub. Date: **May 2, 2002**

(51) **Int. Cl.**
H04K 1/10 (2006.01)

(52) **U.S. Cl.** **375/260; 375/267; 375/295; 375/299; 455/101; 455/103**

(58) **Field of Classification Search** **375/267, 375/260, 295, 299**
See application file for complete search history.

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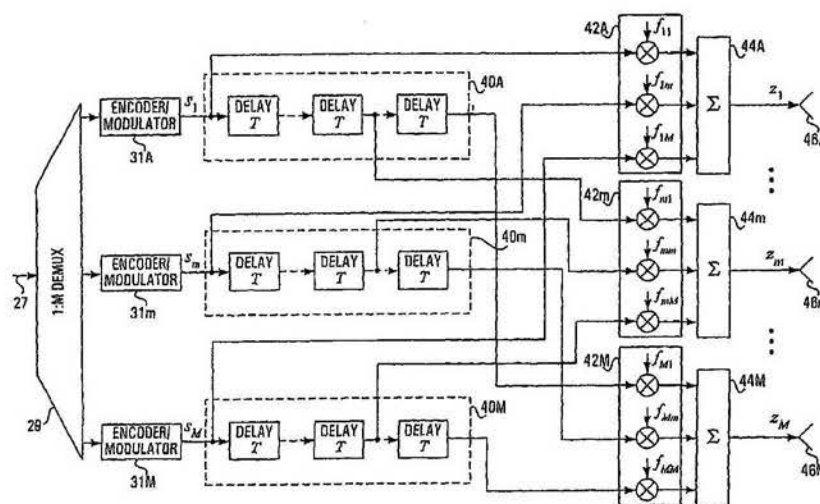
Primary Examiner—Chieh M Fan

Assistant Examiner—Siu M Lee

(57) **ABSTRACT**

It is proposed to combine space-time coding and spatial multiplexing. Also, the use of orthogonal transformation matrices is proposed, which ensures that each bistream contributes to the signal on each antenna.

12 Claims, 8 Drawing Sheets



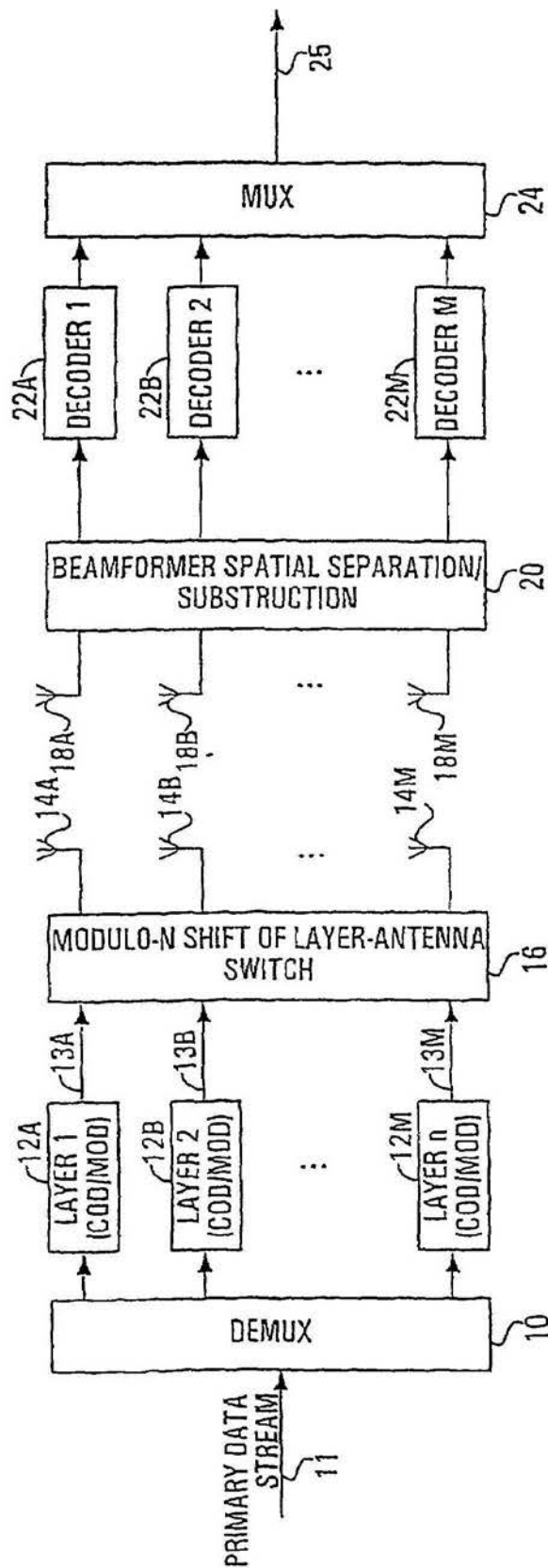


FIG. 1
PRIOR ART

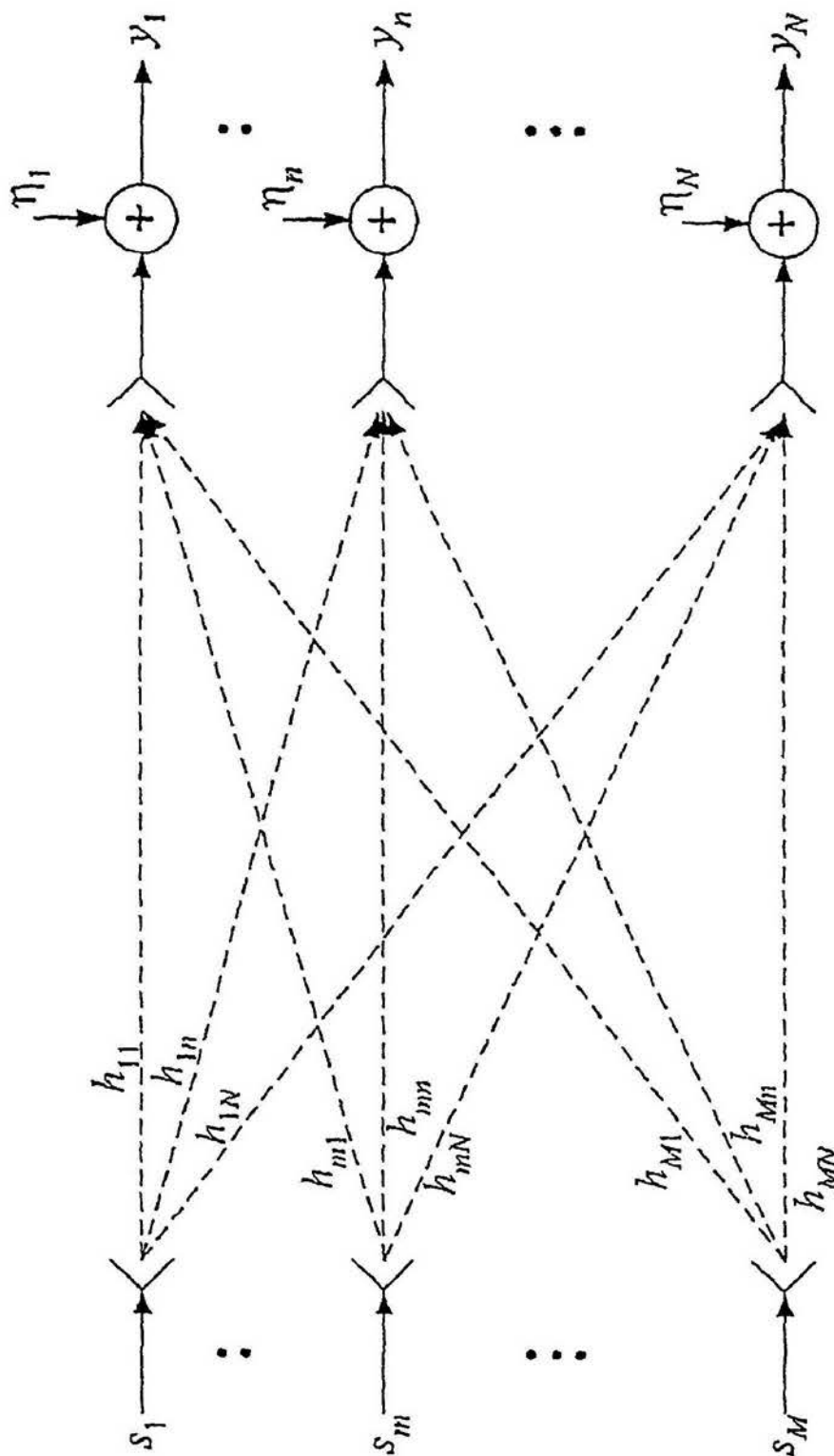


FIG. 2

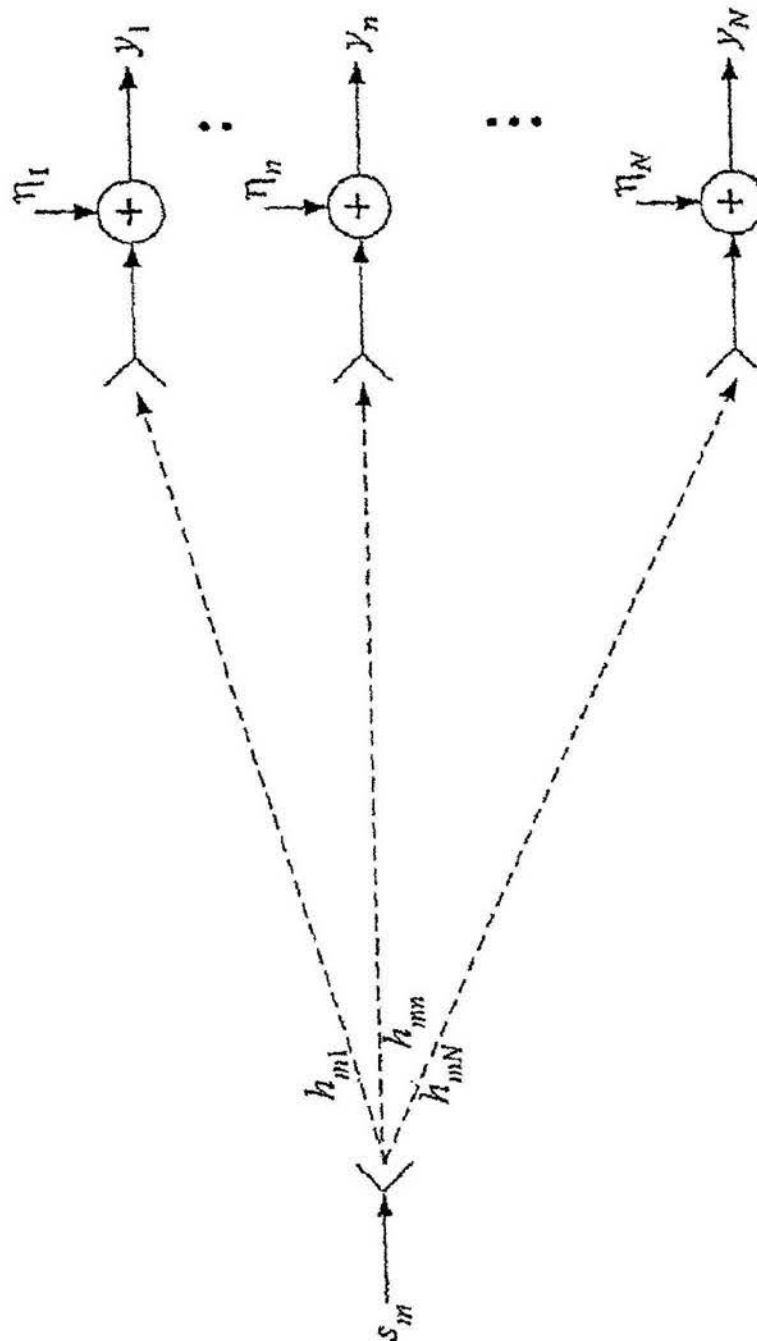


FIG. 3

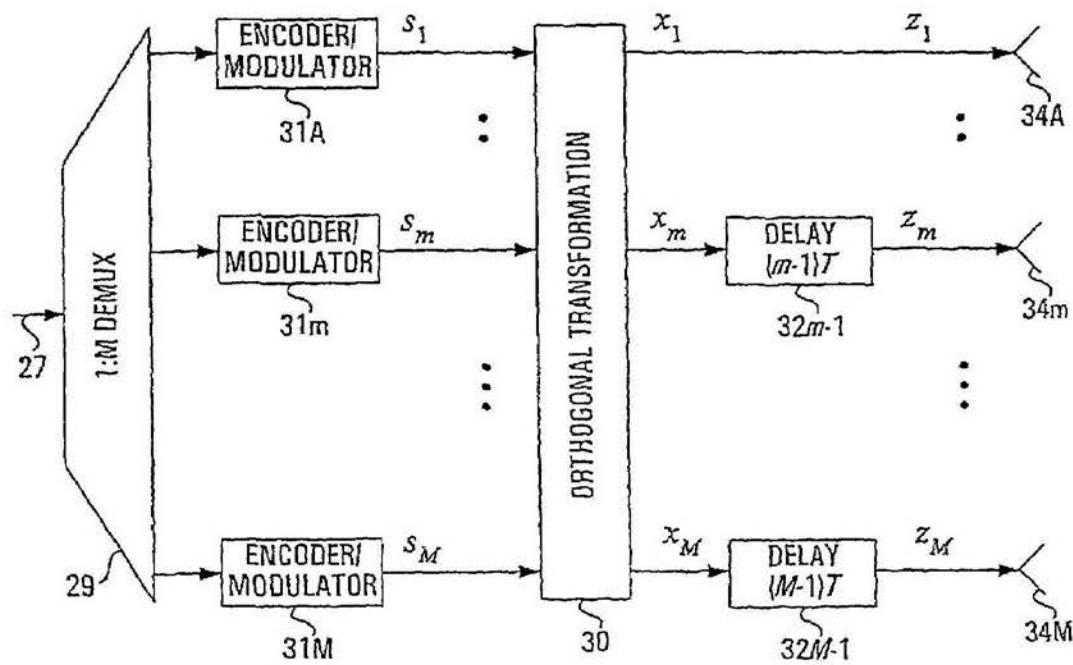


FIG. 4

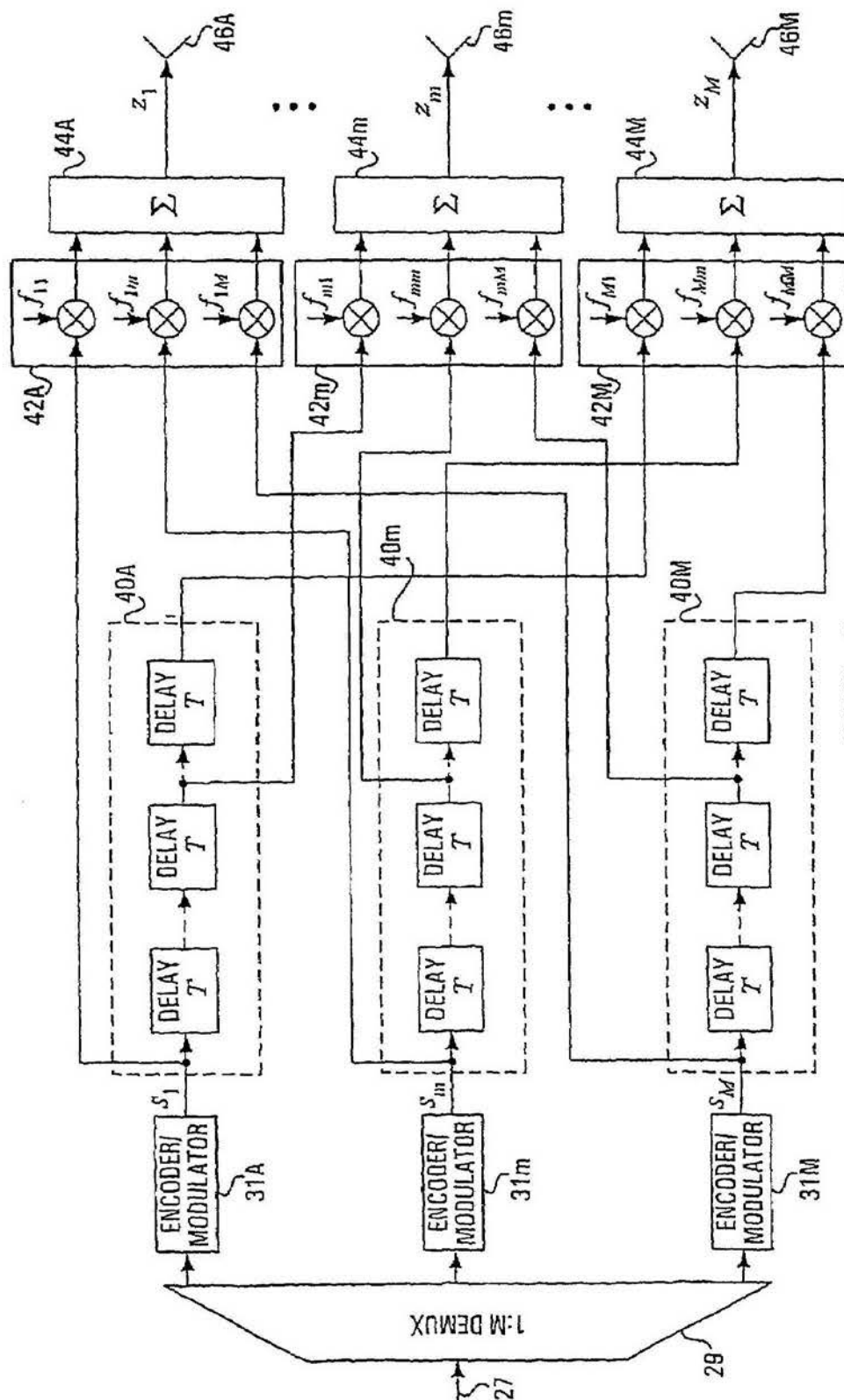


FIG. 5

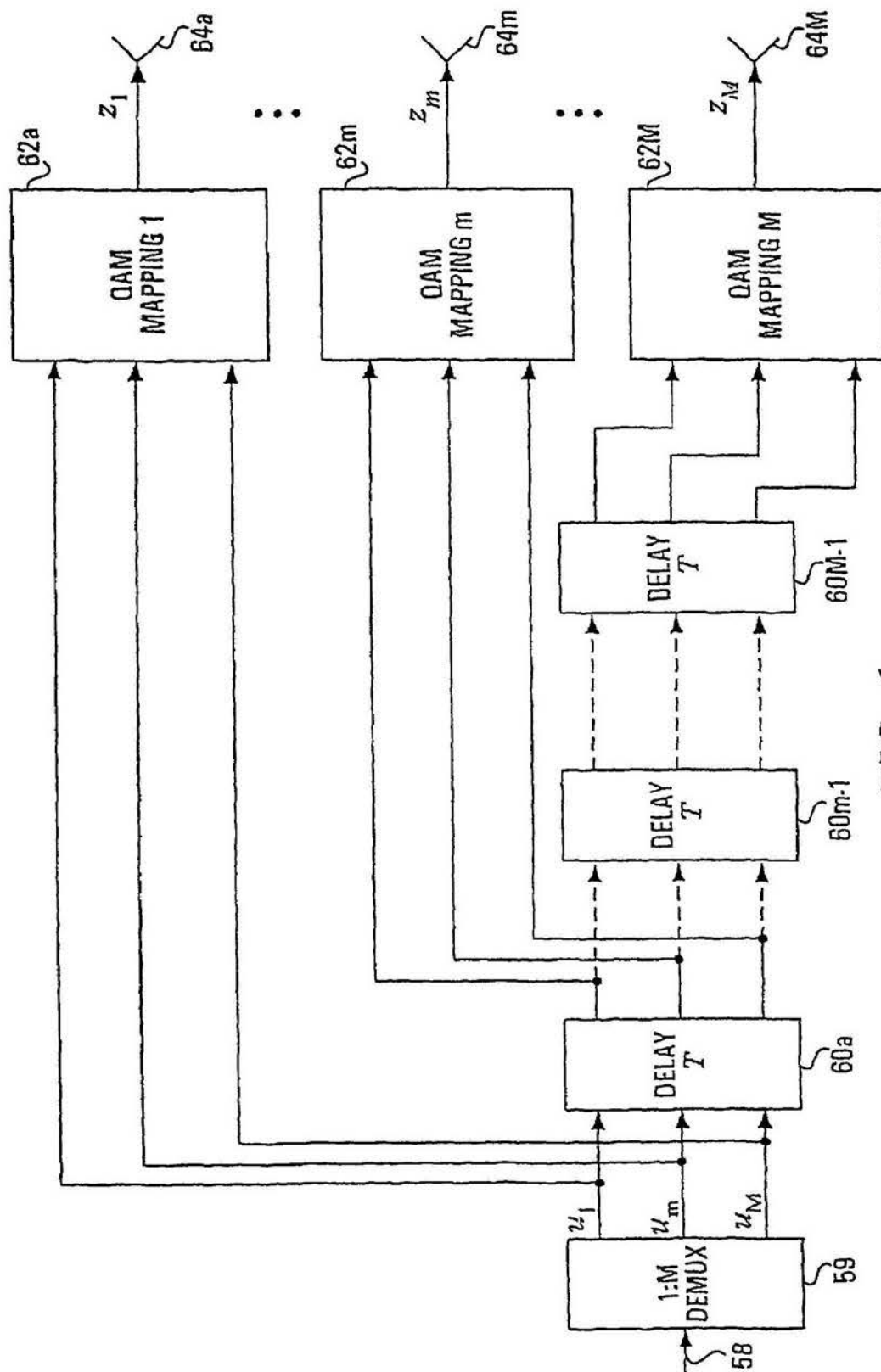


FIG. 6

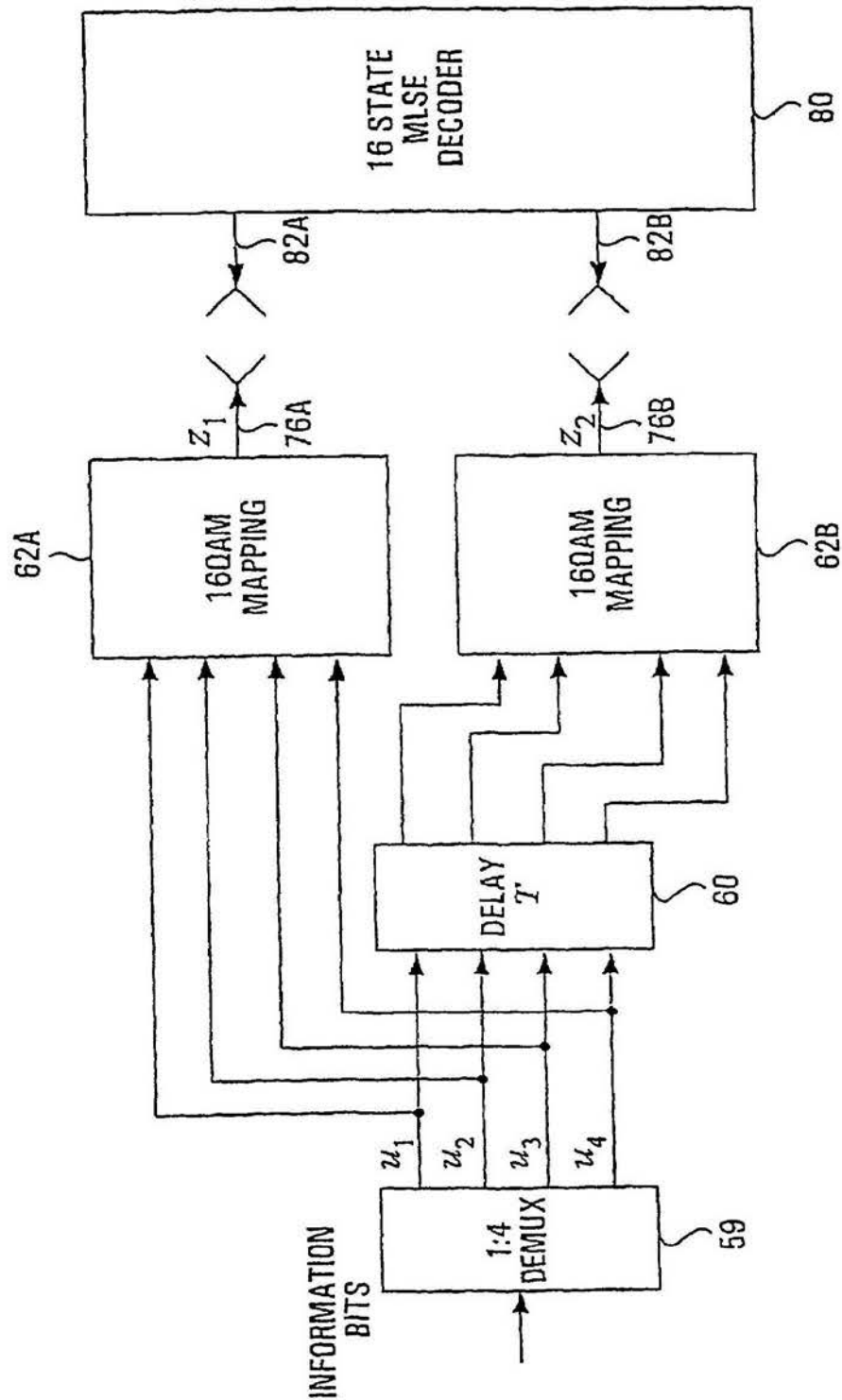


FIG. 7

U.S. Patent

May 5, 2009

Sheet 8 of 8

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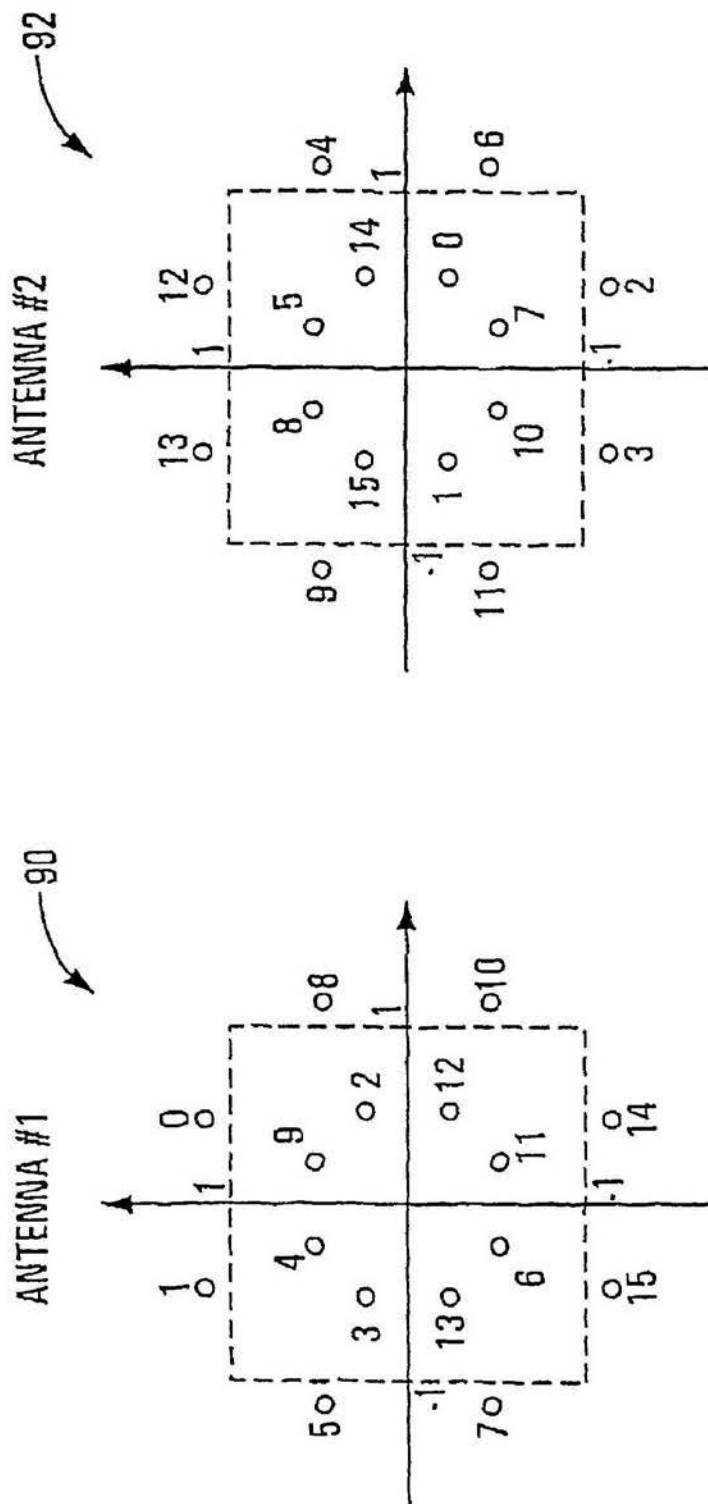


FIG. 8

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COMBINATION OF SPACE-TIME CODING AND SPATIAL MULTIPLEXING, AND THE USE OF ORTHOGONAL TRANSFORMATION IN SPACE-TIME CODING

FIELD OF THE INVENTION

The invention relates to systems and methods for performing layered space-time coding for wireless channels.

BACKGROUND OF THE INVENTION

With the explosion in the demand for wireless Internet services, a number of competing solutions have been developed. UMTS (Universal Mobile Terrestrial Service) standardization has lead to the 3 Gpp standard which offers a 2 Mbps data rate per sector. Work is underway on HSPDA (high speed data access), a higher speed packet data access variation. IS-2000, an evolution of IS-95 provides HDR (High Speed Data Rate) and 1XEV (1X Evolution) which allow wireless Internet browsing at a rate of 7.2 Mbps per sector. Notwithstanding these solutions, there is still the demand to push rates higher.

Recently, it has been proposed to use BLAST (Bell Labs Layered Space Time) which is a layered space-time coding approach, as a wireless data solution. Referring to FIG. 1, the basic concept behind this layered space-time coding approach involves, at the transmit side, a demultiplexer 10 which demultiplexes a primary data stream 11 into M data substreams of equal rate. Each of the M data streams is then encoded and modulated separately in respective coding/modulating blocks 12 (12A, 12B, . . . , 12M) to produce respective encoded and modulated streams 13 (13A, 13B, . . . , 13M). There are M transmit antennas 14 (14A, 14B, . . . , 14M). A switch 16 periodically cycles the association between the modulated streams 13A, 13B, . . . , 13M and the antennas 14A, 14B, . . . , 14M. At the receive side, there are M antennas 18 (18A, 18B, . . . , 18M) which feed into a beamforming/spatial separation/substruction block 20 which performs a spatial beamforming/nulling (zero forcing) process to separate the individual coded streams and feeds these to respective individual decoders 22 (22A, 22B, . . . , 22M). The outputs of the decoders 22A, 22B, . . . , 22M are fed to a multiplexer 24 which multiplexes the signals to produce an output 25 which is an estimate of the primary data stream 11.

There are a number of variations on this architecture. One is to modify the receiver antenna pre-processing to carry out MMSE (minimum mean square error) beamforming rather than nulling in order to improve the wanted signal SNR (signal-to-noise ratio) at the expense of slightly increased ISI (inter-symbol interference). Both the MMSE and nulling approaches normally have the disadvantage that some sort of diversity of the receiver antenna array is necessarily sacrificed in the beamforming process. In order to overcome this problem, layering of the receiver processing can be employed such that after the strongest signal has been decoded (typically using the Viterbi MLSE (maximum likelihood sequence estimation) algorithm) it is subtracted from the received antenna signals in order to remove the strongest signal. This process is iterated down until detection of the weakest signal requires no nulling at all, and its diversity performance is therefore maximized. A disadvantage with this layered approach is the same as that with all subtractive multi-user detection schemes, that the wrong subtraction can cause error propagation.

There are several types of layered space-time coding structures, including horizontal BLAST (H-BLAST), diagonal BLAST (D-BLAST) and vertical BLAST. They have identical

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performance for both optimal linear and non-linear receivers, assuming error control coding is not used in such systems. For optimal linear reception (linear maximum likelihood), these structures have the same SNR performances as those with only a single transmit antenna and a single receive antenna, but do offer the advantage of improved spectral efficiency.

In order to achieve this improved spectral efficiency, in such systems it would be advantageous to have a large number of transmit and receive antennas, for example four of each. However, while this may be practical for larger wireless devices such as laptop computers, it is impractical for smaller hand-held devices because it is not possible to get the antennas far enough apart to ensure their independence. Because of this, for hand-held devices, a practical limit might be two transmit and two receive antennas. Also, another factor limiting the practical number of antennas is cost. Typically about two thirds of the cost of a base station transceiver is in the power amplifier plus antennas, and this will increase if more antennas are added. These factors make only a two by two system commercially practical.

By way of example, consider a system with M transmit and N receive antennas in a frequency non-selective, slowly fading channel. The sampled baseband-equivalent channel model is given by

$$Y=HS+\eta$$

where $H \in \mathbb{C}^{N \times M}$ is the complex channel matrix with the (i,j) -th element being random fading between the i -th receive and j -th transmit antenna. $\eta \in \mathbb{C}^N$ is the additive noise source and is modelled as a zero mean circularly symmetric complex Gaussian random vector with statistically independent elements, that is $\eta \sim \text{CN}(0, 2\sigma_\eta^2 I_N)$. The i -th element of $S \in \mathbb{C}^M$ is the symbol transmitted at the i -th transmit antenna and that of $Y \in \mathbb{C}^N$ is the symbol received at the i -th received antenna. The model is shown in FIG. 2.

That such a system has no improvement in SNR performance can be explained by noting that the data symbol s_m is transmitted only by one antenna, and in case of full cancellation of other transmit antennas, the model of such a system is shown in FIG. 3. In this case there is one transmit antenna and N receive antennas. Therefore, for symbol S_m there is no coding gain.

It would be advantageous to have a layered space-time coding structure which provides the improved spectral efficiency, but which also provides improved SNR performance.

SUMMARY OF THE INVENTION

Embodiments of the invention provide coding gain systems and methods which feature combined space-time coding and spatial multiplexing, and transmitters adapted to include such functionality. The space-time coding introduces a coding gain, and makes symbols more immune to fading since each information component is represented somehow in each spatial output. In some embodiments, the space-time coding comprises a layered space-time architecture. Advantageously, these solutions are amenable to implementation with two transmit antennas and two receive antennas, a configuration suitable for hand-held devices.

According to one broad aspect, the invention provides a coding gain system adapted to transmit a plurality M of symbol substreams. The coding gain system has a space-time coding function adapted to produce M space-time coded streams, with each symbol of the M symbol substreams being represented in all M space-time coded streams and at different

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times. In some embodiments, the coding gain system provided by the invention can be considered to include M transmit antennas each adapted to transmit a respective one of the M space-time coded streams, and/or demultiplexing and encoding functionality adapted to produce the M symbol substreams from a primary input stream.

In some embodiments, the space-time coding function has an orthogonal transform adapted to produce M orthogonal outputs each of which is a function of the M substreams, and has delay elements adapted to insert delays in the M orthogonal outputs to produce M delayed orthogonal outputs such that each of the M delayed orthogonal outputs is a function of a given element of each of the M substreams at a different time. For example, the delay elements can be adapted to introduce a delay of $m-1$ symbol periods in the m th orthogonal output, where $m=1, \dots, M$.

In another embodiment, the space-time coding function has delay elements adapted to insert a delay of $M-1$ symbol periods in each of the M substreams, and an orthogonal transform adapted to produce M orthogonal outputs, with the m th orthogonal output being a function of the M substreams delayed in the delay elements by $m-1$ symbol periods.

In some embodiments the M substreams are non-binary symbols. In other embodiments the M substreams are bit streams. In these embodiments, the orthogonal transform comprises orthogonal symbol mappings, for example M 2^M QAM or MPSK mapping functions, each adapted to produce a respective sequence of M-ary symbols with the M-ary symbol of the m th 2^M QAM mapping function being a function of the M substreams delayed in said delay elements by $m-1$ bit periods.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention will now be described with reference to the attached drawings in which:

FIG. 1 is a block diagram of a known space-time coding system;

FIG. 2 is a channel model for the system of FIG. 1;

FIG. 3 is a channel model for a single antenna output of the system of FIG. 1;

FIG. 4 is a block diagram of a transmitter featuring a coding gain system provided by an embodiment of the invention;

FIG. 5 is a block diagram of a transmitter featuring a coding gain system provided by another embodiment of the invention;

FIG. 6 is a block diagram of a transmitter featuring a coding gain system provided by another embodiment of the invention;

FIG. 7 is a block diagram of a transmitter featuring a coding gain system provided by another embodiment of the invention; and

FIG. 8 is a constellation diagram for the 16 QAM Gray mappings of FIG. 7.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the invention provide a layered space-time architecture with additional gain provided with space-time coding. To achieve this each information symbol s_m is arranged to as to be represented on all M Transmit Antennas. An algorithm of space-time coding is developed for one transmitter, and aggregated with algorithms for M transmitters, so that the spectral efficiency expected for conventional BLAST architecture is retained.

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A range of coding gain methods/systems and transmitters are provided which combine space time coding and spatial multiplexing. Referring firstly to FIG. 4, shown is a space-time coder/multiplexer coding gain system consisting of a 1:M demultiplexer 29 having a single primary input 27 and having M outputs which are each coded and modulated in respective encoder/modulator blocks 31A, ..., 31M to produce encoded substreams $s_1, s_2, \dots, s_M$. There is an orthogonal transformation block 30 and a number of delay blocks 32 (only two shown, 32 $m-1$, 32M-1) the outputs of which are connected to respective transmit antennas 34A, ..., 34M. The orthogonal transformation block 30 has as its inputs the M encoded and modulated substreams $s_1, s_2, \dots, s_M$. The orthogonal transformation block 30 performs the following matrix transform on the input substreams at each symbol interval:

$$X=FS,$$

where $S=(s_1, s_2, \dots, s_M)$ at a given instant, $X=(x_1, x_2, \dots, x_M) \in C^M$ is the output of the orthogonal transformation block 30; and $F \in C^{M \times M}$ is a complex matrix defining the orthogonal transformation. In one embodiment, the (i,m)-th element of F is defined by:

$$f_{im} = (\text{Had}(i,m) \cdot e^{j(n(m-1))/(2M)}) / (\sqrt{M}),$$

where $\text{Had}(i,m) \in \{1, -1\}$ is the (i,m)-th element of the Hadamard matrix. For $M=2$ this matrix is

$$F = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & e^{j\pi/4} \\ 1 & -e^{j\pi/4} \end{bmatrix}.$$

However, this transformation matrix is not unique, this being only an example of a suitable orthogonal transformation. The optimization and/or search for the best of transformation matrix depends on the modulation for initial symbols s_m and on the number of antennas M. It is important that each output of the orthogonal transformation be a function of all the instantaneous inputs. In other words, $x_1=f_1(s_1, s_2, \dots, s_M), \dots, x_M=f_M(s_1, s_2, \dots, s_M)$.

Now, to achieve the separation in time, the m th orthogonal transformation output x_m is delayed by a time period equal to $(m-1)T$, where T is the symbol duration, such that the first output x_1 experiences no delay, and the M th output x_M experiences a delay of $(M-1)T$. The output of the delay blocks 32 consists of the symbols $z_1, \dots, z_M$ to be transmitted on the antennas 34. The effect of the orthogonal transformation 30 plus the delay blocks 32 is that the m th input symbol s_m is represented in all m output streams, but at different times.

Referring now to FIG. 5, another embodiment of the invention is provided in which the encoded and modulated symbols s_m are fed through respective delay banks 40 (40A, ..., 40M) each containing M-1 delay elements. Each symbol with equal delay is fed to a common scaling block 42. Thus, all undelayed symbols $s_1, \dots, s_M$ are fed to a first scaling block 42a, the symbols $s_1, \dots, s_M$ delayed by $(m-1)T$ are fed to an m th scaling block 42m and so on. Each scaling block 42m multiplies each of its inputs by a respective complex multiplier, and the results are summed in a respective summer 44m the output of which is the m th transmitted symbol z_m . This is really mathematically equivalent to the embodiment of FIG. 4 in that each output symbol z_m is again a function of all of the input symbols at a given instant, but at different times. Effectively, the delay block and the orthogonal transformation functions have been done in reverse order.

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Both the examples of FIGS. 4 and 5 perform symbol level space-time encoding in the sense that the input to the space-time encoding process consists of symbols output by the encoder/modulator blocks. Referring now to FIG. 6, another embodiment of the invention is provided in which bit-level space-time encoding is performed. In this embodiment, a 1:M demultiplexer 59 produces from an input bit stream 58 M bit substreams $u_1, \dots, u_M$ which are all fed into delay elements 60A, ..., 60M-1 each adding a further bit period T delay. The undelayed bits $u_1, \dots, u_M$, and the bits output by each of the delay elements 60A, ..., 60M-1 are fed to respective symbol mapping functions 62A, ..., 62M which in the illustrated embodiment are QAM functions. Each QAM mapping function 62A, ..., 62M maps its M input bits to a corresponding output symbol z_m which is output by corresponding antennas 64A, ..., 64M. In one embodiment, the QAM mappings are designed such that they are orthogonal to each other.

Referring now to FIG. 7 a specific example of the embodiment of FIG. 6 is shown which is a very practical embodiment, and in which the same numbering scheme as FIG. 6 is used. In this case, it is assumed that the demultiplexer 59 is a 1:4 demultiplexer which produces four bit substreams u_1, u_2, u_3, u_4 which are all fed undelayed to a first 16 QAM mapping 62A, and are all fed to a delay element 60 which introduces a delay T into the substreams and outputs the delayed substreams into a second 16 QAM mapping 62B. The two QAM mappings 62A, 62B have outputs z_1, z_2 fed to respective transmit antennas 64A, 64B. Details of an example receiver are shown in which there is a 2^M state MLSE decoder 80 connected to two receive antennas 82A, 82B. It is to be understood that many different receiver structures can be used, and this is not important to the invention. This implementation lends itself to efficient implementation in handheld devices because there are only two transmit and two receive antennas.

A recommended mapping for the 16 QAM mapping functions 62A, 62B is shown in FIG. 8. A first mapping is shown for the first antenna 64A, generally indicated by 90. A second mapping is shown for the second antenna 64B, generally indicated by 92. Each mapping shows how the 16 16QAM constellation points, defined by their position on the horizontal (real) and vertical (imaginary) axes, map to corresponding decimal versions (0 to 15) of input bit combinations u_1, u_2, u_3, u_4 (0000 to 1111).

In one example above, the receiver is a 2^M state MLSE decoder. As indicated previously, the particular receiver design is not important. It may be a Viterbi decoder, an iterative decoder, or some other type of decoder.

In the above embodiments, for symbol level space-time coding, it is assumed that the input to the space-time functionality consists of encoded and modulated symbol streams. In another embodiment, the encoding and modulation is integrated with the space-time coding.

Numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practised otherwise than as specifically described herein.

We claim:

1. A transmitter adapted to process a plurality M of symbol substreams, the transmitter comprising:

a space-time coding block adapted to produce M space-time coded symbols per input set of M symbols, each input set of M symbols comprising one symbol per symbol substream, each of the M space-time coded symbols being included in a respective one of M space-time coded streams, wherein each symbol of the M symbol

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substreams is represented in all M space-time coded streams, wherein the transmitter comprises a delay arrangement, arranged such that for each symbol of the M symbol substreams a time of representation of the symbol in the M space-time coded streams is different for each of the M space-time coded streams, each space-time coded symbol comprising a representation of a symbol of each of the M symbol substreams;

a plurality M of transmit antennas each adapted to transmit a respective one of the M space-time coded streams, such that for each symbol of each input set of M symbols, the M space-time coded symbols that contain a representation of the symbol are transmitted at different times.

2. A transmitter according to claim 1 further comprising a demultiplexing and encoding block comprising a demultiplexer having M outputs, and M encoder/modulators each producing a respective one of the M symbol substreams, with each of the M encoder/modulators connected to receive a respective one of the demultiplexer outputs.

3. A transmitter according to claim 2 wherein the demultiplexing and encoding block is adapted to produce the M symbol substreams from an input stream.

4. A transmitter according to claim 3 wherein the space-time coding block comprises:
an orthogonal transform adapted to produce M orthogonal outputs each of which is a function of the M substreams; wherein the delay arrangement comprises delay elements adapted to insert a respective different delay in M-1 of the M orthogonal outputs to produce the M space-time coded streams.

5. A transmitter according to claim 4 wherein the delay elements are adapted to introduce a delay of m-1 symbol periods in the mth orthogonal output, where $m=1, \dots, M$.

6. A transmitter according to claim 1 wherein the delay arrangement comprises:

delay elements adapted to insert a delay in at least one of the M substreams; and

the space-time coding function further comprises an orthogonal transform adapted to produce M orthogonal outputs, with the mth orthogonal output being a function of the M substreams delayed in said delay elements by m-1 symbol periods.

7. A transmitter according to claim 6 wherein the M substreams are bit streams, and wherein the orthogonal transform comprises M M-ary mapping functions, each adapted to produce a respective sequence of M-ary symbols with the M-ary symbol of the mth M-ary mapping function being a function of the M substreams delayed in said delay elements by m-1 bit periods.

8. A method comprising:

demultiplexing an input symbol stream into M symbol substreams;

performing coding and modulation on each of said M symbol substreams;

performing a space-time coding function adapted to produce M space-time coded symbols per input set of M symbols, each input set of M symbols comprising one symbol per symbol substream, each of the M space-time coded symbols being included in a respective one of M space-time coded streams, wherein each symbol of the M symbol substreams is represented in all M space-time coded streams, wherein performing the space-time coding function comprises implementing a delay function, arranged such that for each symbol of the M symbol substream, a time of representation of the symbol in the M space-time coded streams is different for each of the

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M space-time coded streams, each space-time coded symbol comprising a representation of a symbol of each of the M symbol substreams;

transmitting the M space-time coded streams on respective antennas, such that for each symbol of each input set of M symbols, the M space-time coded symbols that contain a representation of the symbol are transmitted at different times.

9. A method according to claim 8 wherein performing the space-time coding function comprises:

executing an orthogonal transform to produce M orthogonal outputs each of which is a function of the M substreams; and

implementing the delay function comprises delaying the M orthogonal outputs to produce M delayed orthogonal outputs such that each of the M delayed orthogonal outputs is a function of a given element of each of the M substreams at a different time.

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10. A method according to claim 9 wherein the mth orthogonal output is delayed by m-1 symbol periods, where $m=1, \dots, M$.

11. A method according to claim 8 wherein performing the space-time coding function comprises:

delaying at least one of the M substreams

executing an orthogonal transform adapted to produce M orthogonal outputs, with the mth orthogonal output being a function of the M substreams delayed m-1 symbol periods.

12. A method according to claim 11 wherein the M substreams are bit streams, and wherein the orthogonal transform comprises M M-ary mapping functions, each adapted to produce a respective sequence of M-ary symbols with the M-ary symbol of the mth M-ary mapping function being a function of the M substreams delayed in said delay elements by m-1 bit periods.

* * * * *

EXHIBIT F



US009313065B2

(12) **United States Patent**
Zhu et al.

(10) **Patent No.:** **US 9,313,065 B2**

(45) **Date of Patent:** ***Apr. 12, 2016**

(54) **SCATTERED PILOT PATTERN AND CHANNEL ESTIMATION METHOD FOR MIMO-OFDM SYSTEMS**

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(72) Inventors: **Peiyong Zhu**, Kanata (CA); **Wen Tong**, Ottawa (CA); **Jianglei Ma**, Kanata (CA); **Ming Jia**, Ottawa (CA)

(73) Assignee: **BlackBerry Limited**, Waterloo, Ontario (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/608,497**

(22) Filed: **Jan. 29, 2015**

(65) **Prior Publication Data**

US 2015/0180630 A1 Jun. 25, 2015

Related U.S. Application Data

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H04J 11/00 (2006.01)
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(Continued)

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CPC **H04L 27/2613** (2013.01); **H04B 7/04** (2013.01); **H04B 7/0413** (2013.01);

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(58) **Field of Classification Search**

CPC H04B 7/04; H04B 7/0684; H04B 7/0413; H04L 1/0618; H04L 5/0023; H04L 5/0048; H04L 25/022; H04L 27/2627

See application file for complete search history.

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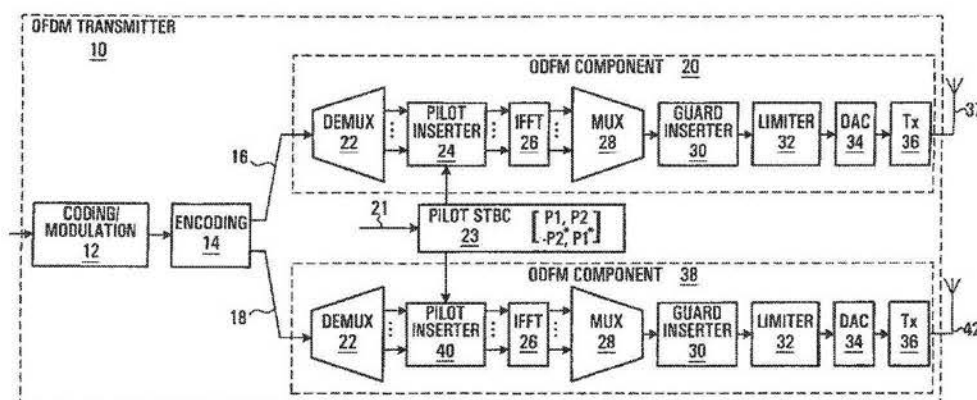
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Primary Examiner — Melanie Jagannathan

(57) **ABSTRACT**

A method and apparatus are provided for reducing the number of pilot symbols within a MIMO-OFDM communication system, and for improving channel estimation within such a system. For each transmitting antenna in an OFDM transmitter, pilot symbols are encoded so as to be unique to the transmitting antenna. The encoded pilot symbols are then inserted into an OFDM frame to form a diamond lattice, the diamond lattices for the different transmitting antennae using the same frequencies but being offset from each other by a single symbol in the time domain. At the OFDM receiver, a channel response is estimated for a symbol central to each diamond of the diamond lattice using a two-dimensional interpolation. The estimated channel responses are smoothed in the frequency domain. The channel responses of remaining symbols are then estimated by interpolation in the frequency domain.

42 Claims, 7 Drawing Sheets



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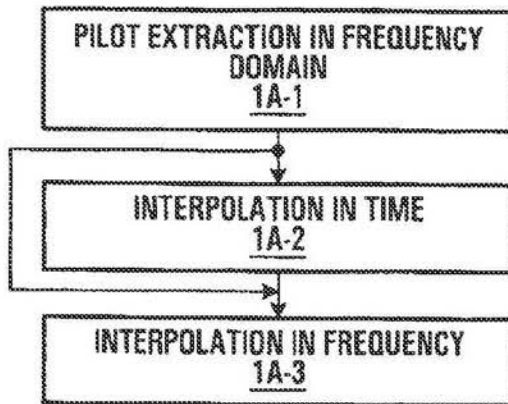


FIG. 1A
(PRIOR ART)

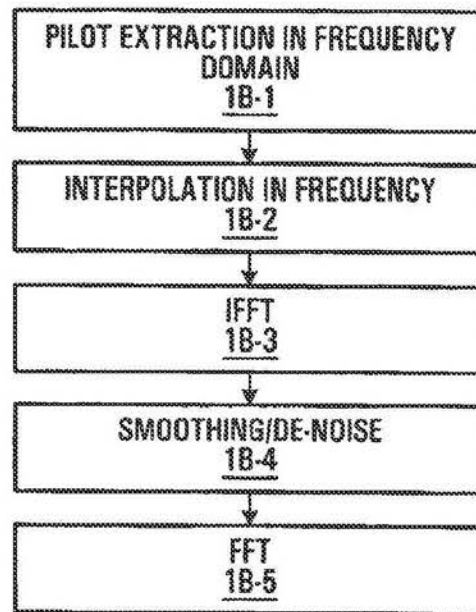


FIG. 1B
(PRIOR ART)

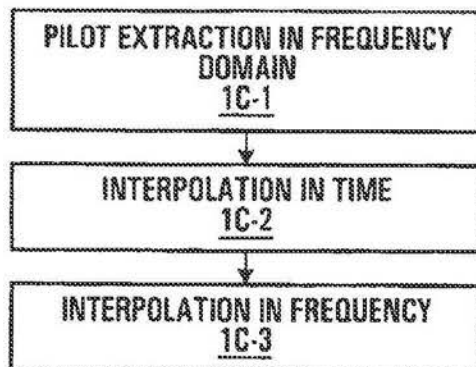


FIG. 1C
(PRIOR ART)

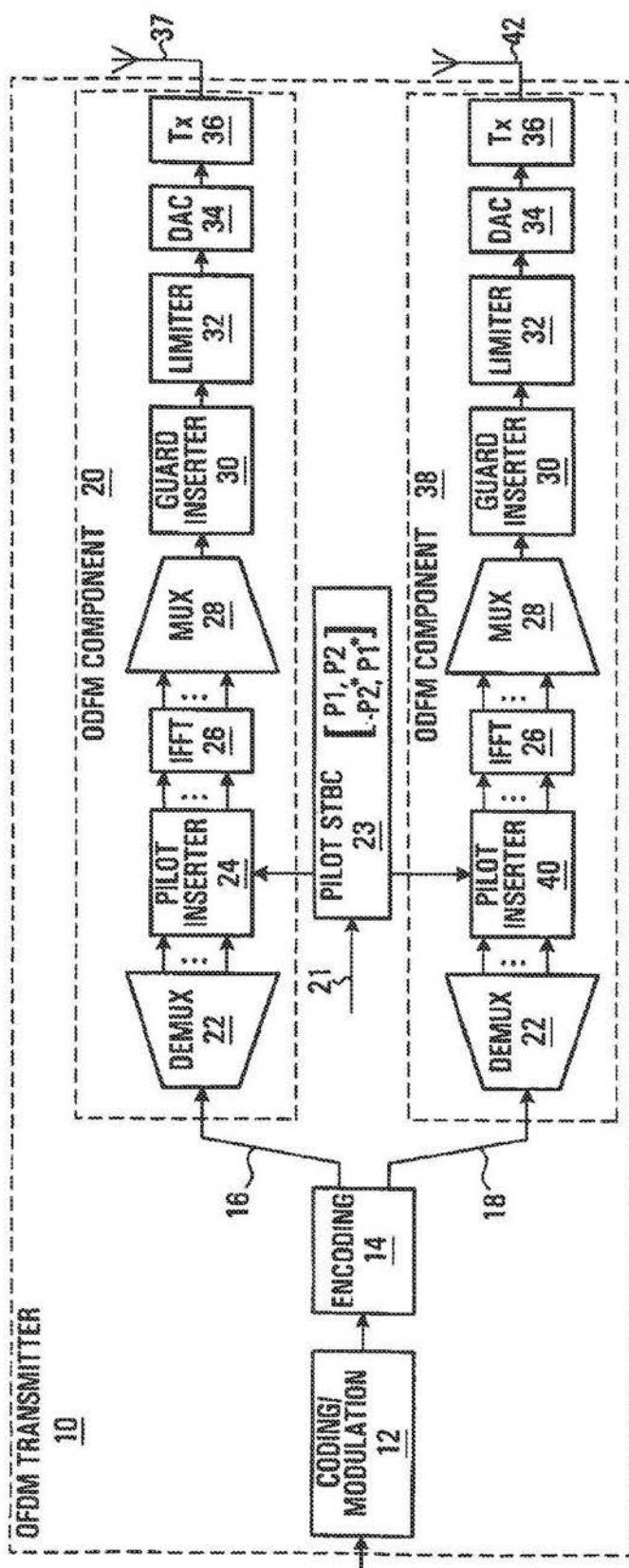


FIG. 2

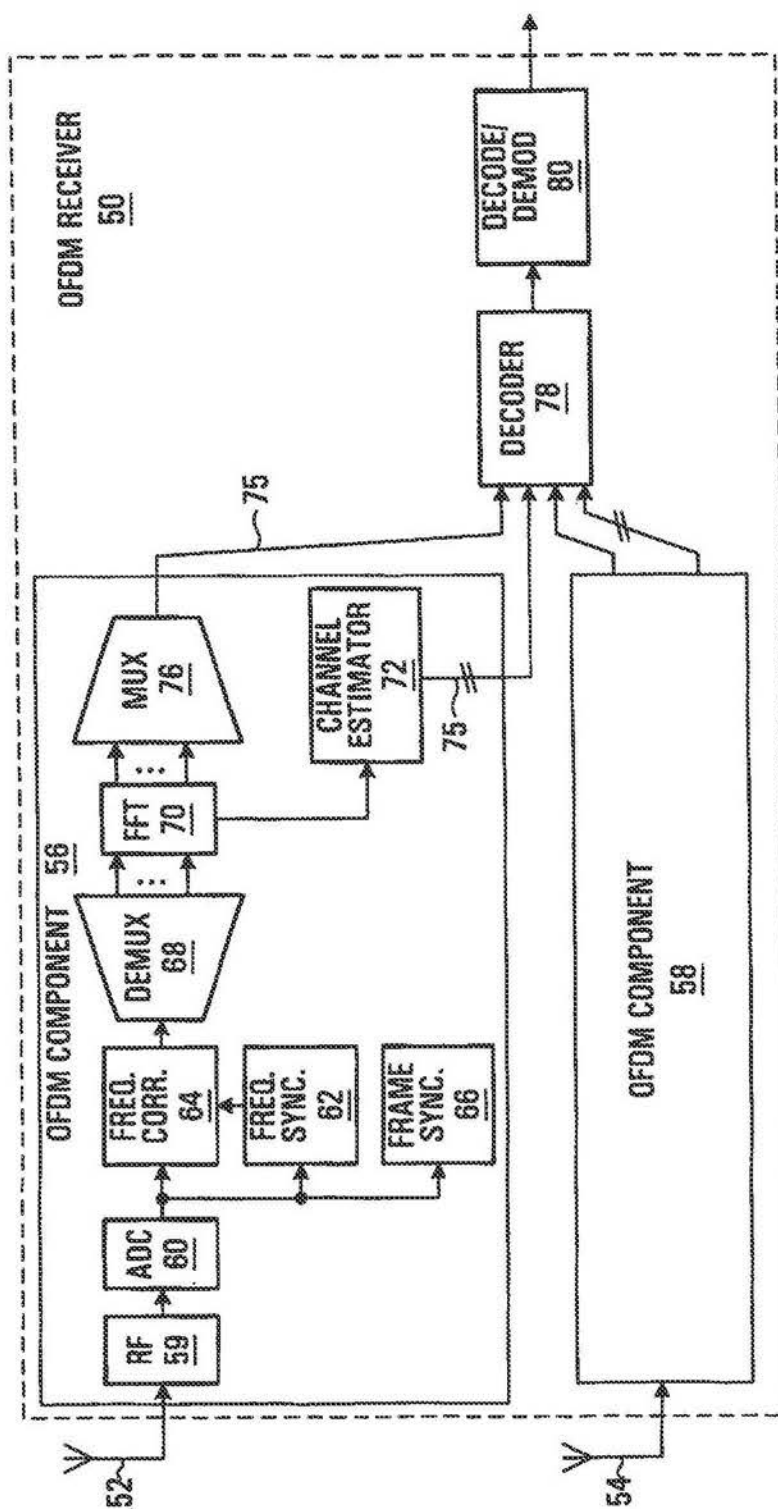


FIG. 3

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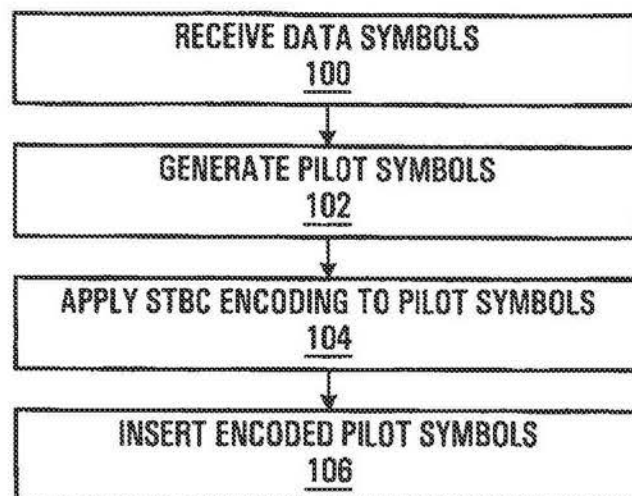


FIG. 4

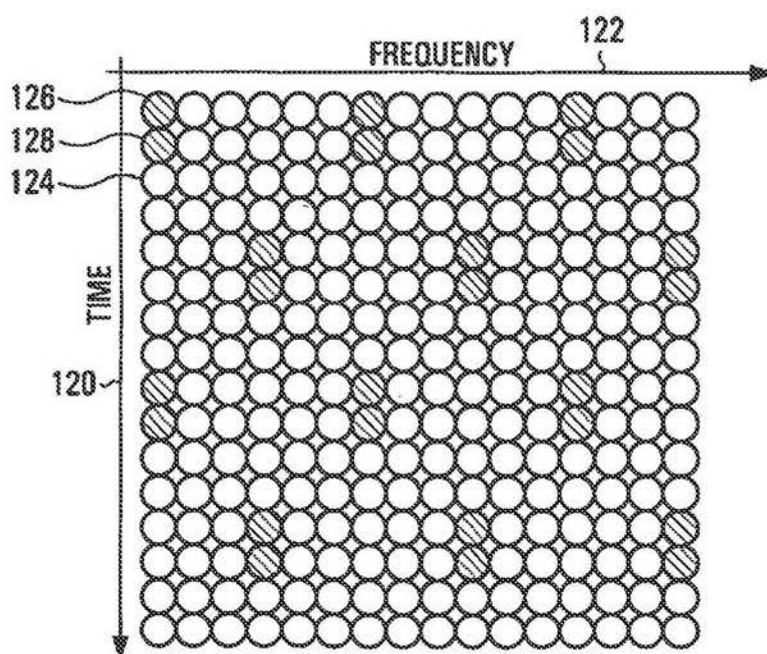


FIG. 5

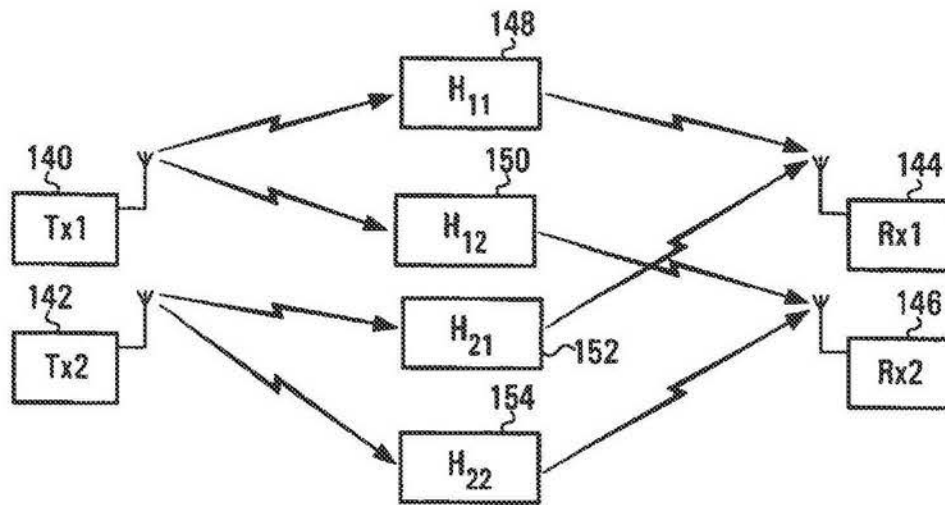


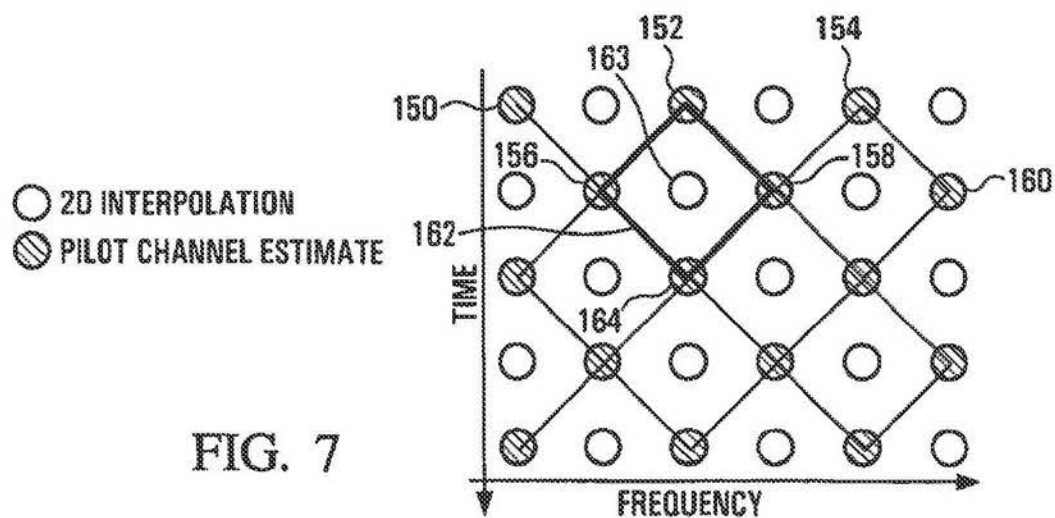
FIG. 6

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○ 2D INTERPOLATION
 ⊗ PILOT CHANNEL ESTIMATE

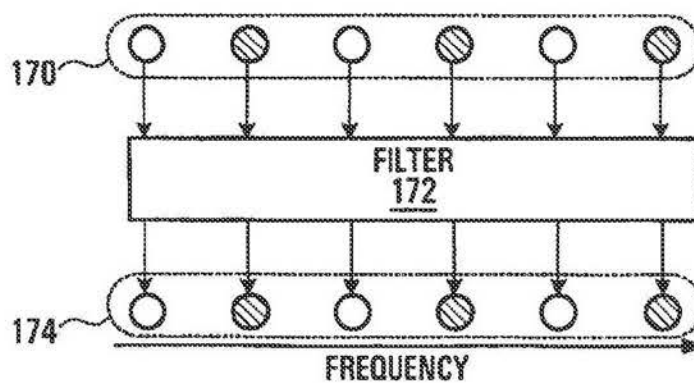


FIG. 8

○ 2D INTERPOLATION
 ⊗ PILOT CHANNEL ESTIMATE
 ⊕ 1D INTERPOLATION

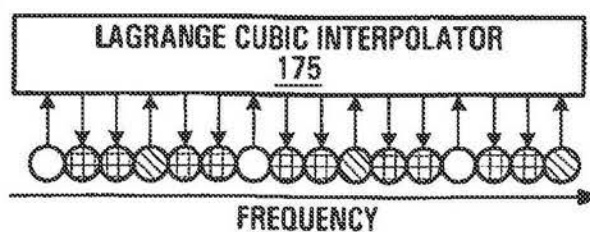


FIG. 9

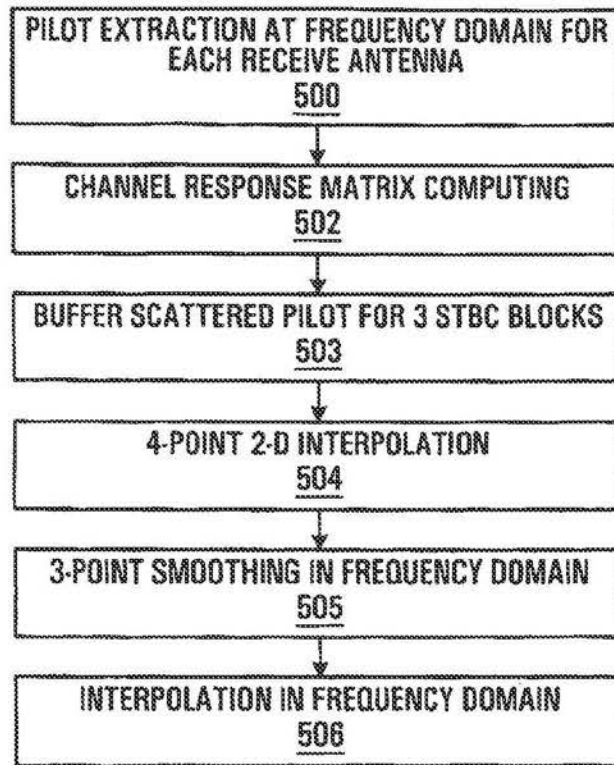


FIG. 10

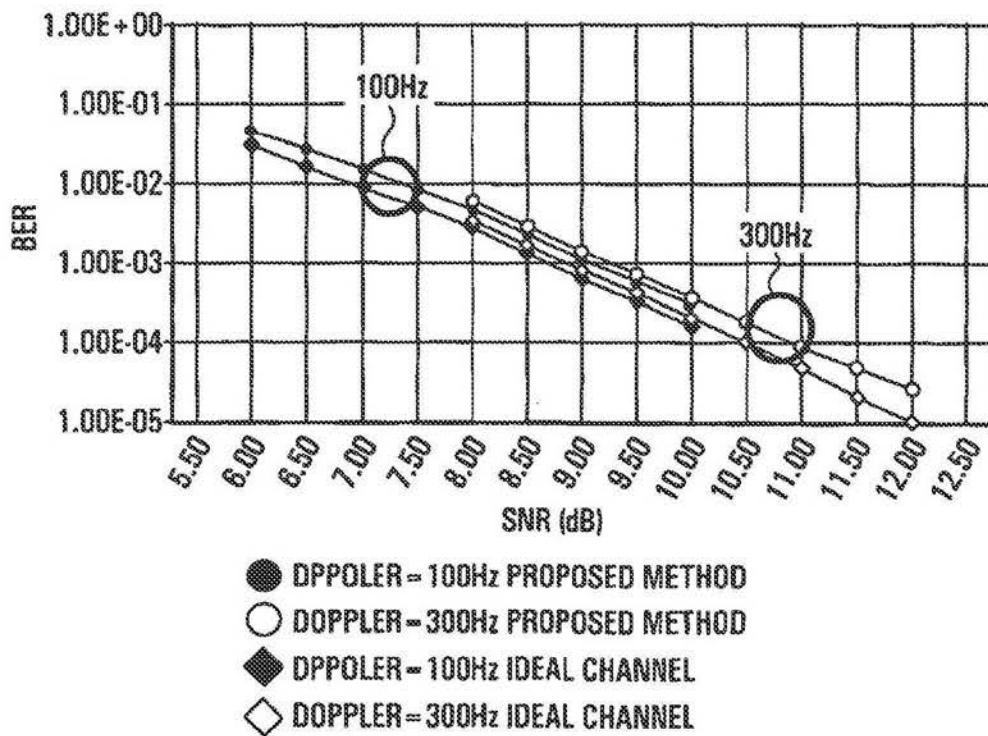


FIG. 11

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SCATTERED PILOT PATTERN AND CHANNEL ESTIMATION METHOD FOR MIMO-OFDM SYSTEMS

RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 14/249,127, filed on Apr. 9, 2014, which is itself is a continuation of U.S. application Ser. No. 13/765,523, filed on Feb. 12, 2013, which is itself is a continuation of U.S. application Ser. No. 13/586,660, filed on Aug. 15, 2012, and issued as U.S. Pat. No. 8,406,118 on Mar. 26, 2013, which is itself is a continuation of U.S. application Ser. No. 12/468,624, filed on May 19, 2009, and issued as U.S. Pat. No. 8,254,246 on Aug. 28, 2012, which is itself a continuation of U.S. application Ser. No. 11/819,690, filed on Jun. 28, 2007 and issued as U.S. Pat. No. 7,545,734 on Jun. 9, 2009, which is itself a continuation of U.S. application Ser. No. 10/038,883, filed on Jan. 8, 2002, which has issued as U.S. Pat. No. 7,248,559 on Jul. 24, 2007, and claims the benefit thereof, which itself claims the benefit of U.S. Provisional Application No. 60/329,509 filed Oct. 17, 2001, the contents of which are incorporated in its entirety herein by reference.

FIELD OF THE INVENTION

This invention relates to OFDM communication systems, and more particularly to a more efficient use of pilot symbols within such systems.

BACKGROUND OF THE INVENTION

Multiple Input Multiple Output-Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is a novel highly spectral efficient technology used to transmit high-speed data through radio channels with fast fading both in frequency and in time.

In wireless communication systems that employ OFDM, a transmitter transmits data to a receiver using many sub-carriers in parallel. The frequencies of the sub-carriers are orthogonal. Transmitting the data in parallel allows the symbols containing the data to be of longer duration, which reduces the effects of multi-path fading. The orthogonality of the frequencies allows the sub-carriers to be tightly spaced, while minimizing inter-carrier interference. At the transmitter, the data is encoded, interleaved, and modulated to form data symbols. Overhead information is added, including pilot symbols, and the symbols (data plus overhead) are organized into OFDM symbols. Each OFDM symbol typically uses 2^n frequencies. Each symbol is allocated to represent a component of a different orthogonal frequency. An inverse Fast Fourier Transform (IFFT) is applied to the OFDM symbol (hence the preference of 2^n frequencies) to generate time samples of a signal. Cyclic extensions are added to the signal, and the signal is passed through a digital-to-analog converter. Finally, the transmitter transmits the signal to the receiver along a channel.

When the receiver receives the signal, the inverse operations are performed. The received signal is passed through an analog-to-digital converter, and timing information is then determined. The cyclic extensions are removed from the signal. The receiver performs an FFT on the received signal to recover the frequency components of the signal, that is, the data symbols. Error correction may be applied to the data symbols to compensate for variations in phase and amplitude caused during propagation of the signal along the channel.

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The data symbols are then demodulated, de-interleaved, and decoded, to yield the transmitted data.

In systems employing differential detection, the receiver compares the phase and/or amplitude of each received symbol with an adjacent symbol. The adjacent symbol may be adjacent in the time direction or in the frequency direction. The receiver recovers the transmitted data by measuring the change in phase and/or amplitude between a symbol and the adjacent symbol. If differential detection is used, channel compensation need not be applied to compensate for variations in phase and amplitude caused during propagation of the signal. However, in systems employing coherent detection the receiver must estimate the actual phase and amplitude of the channel response, and channel compensation must be applied.

The variations in phase and amplitude resulting from propagation along the channel are referred to as the channel response. The channel response is usually frequency and time dependent. If the receiver can determine the channel response, the received signal can be corrected to compensate for the channel degradation. The determination of the channel response is called channel estimation. The inclusion of pilot symbols in each OFDM symbol allows the receiver to carry out channel estimation. The pilot symbols are transmitted with a value known to the receiver. When the receiver receives the OFDM symbol, the receiver compares the received value of the pilot symbols with the known transmitted value of the pilot symbols to estimate the channel response.

The pilot symbols are overhead, and should be as few in number as possible in order to maximize the transmission rate of data symbols. Since the channel response can vary with time and with frequency, the pilot symbols are scattered amongst the data symbols to provide as complete a range as possible of channel response over time and frequency. The set of frequencies and times at which pilot symbols are inserted is referred to as a pilot pattern. The optimal temporal spacing between the pilot symbols is usually dictated by the maximum anticipated Doppler frequency, and the optimal frequency spacing between the pilot symbols is usually dictated by the anticipated delay spread of multi-path fading.

The existing pilot-assisted OFDM channel estimation approaches are designed for conventional one transmitter system. With a scattered pilot arrangement, there are three classes of algorithms:

- 1-D frequency interpolation or time interpolation
- Transformed frequency 1-D interpolation
- Independent time and frequency 1-D interpolation

The first class of algorithms is based on the pilot OFDM symbol (all the sub-carriers are used as the pilots) or comb-type of pilots. This approach shown in the flow chart of FIG. 1A is simple but only suitable for channels with high frequency selectivity or channels with high time fading. The method involves pilot extraction in the frequency domain (step 1A-1) followed by interpolation in time (step 1A-2), or interpolation in frequency (step 1A-3).

The second method shown in the flow chart of FIG. 1B is aimed for channels with slow Doppler fading and fast frequency fading. It improves the first method by using FFT to reconstruct the channel response back to time domain for noise reduction processing at the expense of FFT/IFFT computing for the channel estimation separately. The method begins with pilot extraction in the frequency domain (step 1B-1), which may be followed by interpolation in frequency (step 1B-2). Then an inverse fast Fourier transform (step 1B-3), smoothing/de-noise processing (step 1B-4), and finally a fast Fourier transform (1B-5) steps are executed.

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The third method shown in the flow chart of FIG. 1C can be used to estimate channel for mobile applications, where both fast time fading and frequency fading exist. However it needs a relatively high density of pilots and a completed interpolator. This method involves pilot extraction in the frequency domain (step 1C-1) this is followed by interpolation in time (step 1C-2) and interpolation in frequency (step 1C-3).

In the propagation environment with both high frequency dispersion and temporal fading, the channel estimation performance can be improved by the increase of pilot symbol density at the price of the reduction of the spectral efficiency of the data transmission. To interpolate and reconstruct the channel response function from the limited pilots to achieve reliable channel estimation with the minimum overhead is a challenging task.

There are a variety of existing standard pilot patterns. In environments in which the channel varies only slowly with time and frequency, the pilot symbols may be inserted cyclically, being inserted at an adjacent frequency after each time interval. In environments in which the channel is highly frequency dependent, the pilot symbols may be inserted periodically at all frequencies simultaneously. However, such a pilot pattern is only suitable for channels that vary very slowly with time. In environments in which the channel is highly time dependent, the pilot symbols may be inserted continuously at only specific frequencies in a comb arrangement to provide a constant measurement of the channel response. However, such a pilot pattern is only suitable for channels that vary slowly with frequency. In environments in which the channel is both highly frequency and highly time dependent (for example, mobile systems with much multi-path fading), the pilot symbols may be inserted periodically in time and in frequency so that the pilot symbols form a rectangular lattice when the symbols are depicted in a time-frequency diagram.

In OFDM communication systems employing coherent modulation and demodulation, the receiver must estimate the channel response at the frequencies of all sub-carriers and at all times. Although this requires more processing than in systems that employs differential modulation and demodulation, a significant gain in signal-to-noise ratio can be achieved using coherent modulation and demodulation. The receiver determines the channel response at the times and frequencies at which pilot symbols are inserted into the OFDM symbol, and performs interpolations to estimate the channel response at the times and frequencies at which the data symbols are located within the OFDM symbol. Placing pilot symbols more closely together (in frequency if a comb pattern is used, in time if a periodic pattern is used, or in both frequency and in time if a rectangular lattice pattern is used) within a pilot pattern results in a more accurate interpolation. However, because pilot symbols are overhead, a tighter pilot pattern is at the expense of the transmitted data rate.

Existing pilot patterns and interpolation techniques are usually sufficient if the channel varies slowly with time (for example for nomadic applications). However, if the channel varies quickly with time (for example, for mobile applications), the time interval between pilot symbols must be reduced in order to allow an accurate estimation of the channel response through interpolation. This increases the overhead in the signal.

The problem of minimizing the number of pilot symbols while maximizing the accuracy of the interpolation is also particularly cumbersome in Multiple-Input Multiple-Output (MIMO) OFDM systems. In MIMO OFDM systems, the transmitter transmits data through more than one transmitting antenna and the receiver receives data through more than one receiving antenna. The binary data is usually divided between

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the transmitting antennae, although the same data may be transmitted through each transmitting antenna if spatial diversity is desired. Each receiving antenna receives data from all the transmitting antennae, so if there are M transmitting antennae and N receiving antennae, then the signal will propagate over MxN channels, each of which has its own channel response. Each transmitting antenna inserts pilot symbols into the same sub-carrier location of the OFDM symbol which it is transmitting. In order to minimize interference at the receiver between the pilot symbols of each transmitting antenna, each transmitting antenna typically blinks its pilot pattern on and off. This increases the temporal separation of the pilot symbols for each transmitter, reducing the accuracy of the interpolation used to estimate the channel response. In MIMO-OFDM systems a simple and fast channel estimation method is particularly crucial because of the limitation of the computational power for estimating MxN channels, while in SISO-OFDM system only one channel needs to be estimated.

SUMMARY OF THE INVENTION

Channel estimation methods are provided which are based on the partial interpolation of a scattered pilot by using true 2-D interpolation; and additionally, simple 1-D interpolation is used to reconstruct the entire channels. This method has a reduced scattered pilot overhead, and is at least an order of magnitude less computationally complex than some existing methods. In general, the proposed method of channel estimation is more robust in channels with high Doppler spread, and provides better performance than some existing methods and requires the less buffering of the OFDM symbols for the coherent detection at the receiver than in some methods.

The methods allow fewer pilot symbols to be placed within each OFDM symbol, while still allowing accurate interpolation of the channel response. The data rate of an MIMO-OFDM system is thereby improved.

According to a first aspect of the invention, there is provided a method of inserting pilot symbols into Orthogonal Frequency Division Multiplexing (OFDM) frames transmitted on a plurality N of transmitting antenna, the OFDM frames having a time domain and a frequency domain, each OFDM frame comprising a plurality of OFDM symbols, the method comprising the steps of: for the N transmit antennas, transmitting sets of N pilot symbols, each set being in a location within a scattered pattern in time-frequency, each set of N pilot symbols comprising a pilot symbol for each antenna.

In some embodiments, transmitting sets of N pilot symbols, each set being in a location within a scattered pattern in time-frequency comprises: transmitting a set of N pilot symbols in a respective location within the scattered pattern on a same sub-carrier.

In some embodiments, for the N transmit antennas, transmitting sets of N pilot symbols, each set being in a location within a scattered pattern in time-frequency comprises: inserting sets of N pilot symbols at locations that form at least one diagonal arrangement in time-frequency.

In some embodiments, inserting sets of N pilot symbols comprises: when N is equal to two, for each antenna, alternating insertion of null symbol locations and pilot symbols in the at least one diagonal arrangement for a first antenna of the pair of antennas and alternating insertion of pilot symbols and null symbol locations in the at least one diagonal arrangement for a second antenna of the pair of antennas, wherein the null

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symbol locations of the first antenna correspond to a same location in time-frequency as the pilot symbols of the second antenna, and vice versa.

In some embodiments, the method further comprises for each location within a scattered pattern in time-frequency: generating a group of L uncoded pilot symbols; performing space time block coding (STBC) on the group of L uncoded pilot symbols to produce an $N \times N$ STBC block, L and N determining an STBC code rate; transmitting one row or column of the STBC block on each antenna on a specific sub-carrier.

In some embodiments, the method further comprises transmitting the sets of N pilot symbols with a power level greater than a power level of data symbols, depending upon a value reflective of channel conditions.

In some embodiments, the method further comprises transmitting the sets of N pilot symbols with a power level which is dynamically adjusted to ensure sufficiently accurate reception as a function of a modulation type applied to sub-carriers carrying data.

In some embodiments, transmitting sets of N pilot symbols, each set being in a location within a scattered pattern in time-frequency comprises: providing a first plurality of equally spaced sub-carrier positions; providing a second plurality of equally spaced sub-carrier positions offset from said first plurality; inserting the sets of N pilot symbols alternately in time using the first plurality of equally spaced sub-carrier positions and the second plurality of equally spaced sub-carrier positions.

In some embodiments, the second plurality of equally spaced sub-carrier positions is offset from the first plurality of equally spaced sub-carrier positions by half the spacing between adjacent sub-carriers of the first plurality of sub-carrier positions thereby forming a diamond shaped arrangement.

In some embodiments, the method further comprises inserting sets of N pilot symbols in an OFDM resource for an additional group of N transmitting antennas wherein transmitting sets of N pilot symbols in a respective pattern in time-frequency for the additional group of N transmitting antennas comprises: employing the same respective pattern of pilot symbols as the N transmitting antennas where $N \geq 2$, but offset in at least one of time and frequency.

According to a second aspect of the invention, there is provided a method comprising: providing a first transmitter implementing the method according to the first aspect of the invention; providing at least one other transmitter implementing the method according to the first aspect of the invention using scattered patterns offset from those used by the first transmitter.

According to a third aspect of the invention, there is provided a transmitter comprising: a plurality N of transmit antennas; an OFDM frame generator that inserts pilot symbols into Orthogonal Frequency Division Multiplexing (OFDM) frames transmitted on the plurality N of transmit antennas, the OFDM frames having a time domain and a frequency domain, each OFDM frame comprising a plurality of OFDM symbols, such that for the N transmit antennas, sets of N pilot symbols are transmitted, each set being in a location within a scattered pattern in time-frequency, each set of N pilot symbols comprising a pilot symbol for each antenna.

In some embodiments, a set of N pilot symbols in a respective location within the scattered pattern is transmitted on a same sub-carrier.

In some embodiments, the transmitter is further operable to, for each location in the scattered pattern: generate a group of L uncoded pilot symbols; perform space time block coding

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(STBC) on the group of L pilot symbols to produce an $N \times N$ STBC block; transmit one row or column of the STBC block on each antenna.

In some embodiments, the transmitter is further operable to transmit the sets of N pilot symbols with a power level greater than a power level of data symbols depending on a value reflective of channel conditions.

In some embodiments, the transmitter is further operable to transmit the sets of N pilot symbols with a power level which is dynamically adjusted to ensure sufficiently accurate reception.

In some embodiments, the OFDM frame generator is operable to: define a first plurality of equally spaced sub-carrier locations; define a second plurality of equally spaced sub-carrier locations offset from said first plurality; wherein the sets of N pilot symbols are inserted alternately in time using the first plurality of equally spaced sub-carrier locations and the second plurality of equally spaced sub-carrier locations.

In some embodiments, spacing between locations of the scattered pattern in time-frequency is optimized to allow a fast extraction of scattered pilot symbols without requiring the computation of a complete FFT.

According to a fourth aspect of the invention, there is provided a receiver comprising: a plurality N of receive antennas for receiving OFDM symbols comprising: sets of N pilot symbols transmitted from N antennas in a scattered pattern in time-frequency, the sets of N pilot symbols for each respective pattern in time-frequency inserted such that sets of N pilot symbols from different antennas do not occupy a same location in time-frequency; and data symbols in time-frequency; and a channel estimator for comparing the received sets of N pilot symbols with pilot symbol values known to be transmitted by a transmitter.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying Figures.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in greater detail with reference to the accompanying Figures, in which:

FIG. 1A illustrates a flow-chart of an example for three examples of conventional OFDM Channel Estimation;

FIG. 1B illustrates a flow-chart of another example of conventional OFDM Channel Estimation;

FIG. 1C illustrates a flow-chart of another example of conventional OFDM Channel Estimation;

FIG. 2 is a block diagram of a Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (OFDM) transmitter provided by an embodiment of the invention;

FIG. 3 is a block diagram of an OFDM receiver;

FIG. 4 is a flowchart of a method by which an OFDM transmitter inserts pilot symbols into an OFDM frame according to one embodiment of the invention;

FIG. 5 is a diagram of a pilot pattern generated using the method of FIG. 4;

FIG. 6 is a block diagram of a MIMO system showing the channel transfer functions between two transmit antennas and two receive antennas;

FIG. 7 is a time frequency diagram showing channel estimate positions for pilot channel estimation;

FIG. 8 schematically illustrates a step of filtering estimated and interpolated pilot channel estimates;

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FIG. 9 shows schematically the step of interpolating between the channel estimates previously determined to provide channel estimates for all sub-carriers and all times;

FIG. 10 is a flow chart summarizing the overall channel estimation method provided by an embodiment of the invention; and

FIG. 11 is an example of a set of performance results obtained using the method of FIG. 10.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following sections describe a MIMO-OFDM transmitter/receiver and scattered pilot insertion. By way of introduction, a OFDM frame consists of the preamble OFDM symbols and regular OFDM symbols. Each OFDM symbol uses a set of orthogonal sub-carriers. When there are two transmit antennas, two OFDM symbols form a STTD block. For regular OFDM symbols, some sub-carriers are used as pilot sub-carriers to carry pilot symbols while the others are used as data sub-carriers to carry data symbols. The pilot sub-carriers are modulated by pilot symbols generated by QPSK. The data sub-carriers are modulated by complex data symbols generated by QAM mapping. STTD coding is applied to the pilot sub-carrier pairs located at the same frequency within one STTD block.

Referring to FIG. 2, a block diagram of a Multiple-Input Multiple-Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) transmitter provided by an embodiment of the invention is shown. The OFDM transmitter shown in FIG. 2 is a two-output OFDM transmitter, though more generally there may be a plurality of M transmitting antennae. An OFDM transmitter 10 takes binary data as input but data in other forms may be accommodated. The binary data is passed to a coding/modulation primitive 12 responsible for encoding, interleaving, and modulating the binary data to generate data symbols, as is well known to those skilled in the art. The coding/modulation primitive 12 may include a number of processing blocks, not shown in FIG. 2. An encoder 14 applies Space-Time Block Coding (STBC) to the data symbols. The encoder 14 also separates the data symbols into a first processing path 16 and a second processing path 18, by sending alternate data symbols along each of the two processing paths. In the more general case in which the OFDM transmitter 10 includes M transmitting antennae, the encoder 14 separates the data symbols into M processing paths.

The data symbols sent along the first processing path 16 are sent to a first OFDM component 20. The data symbols are first passed to a demultiplexer 22 in the first OFDM component 20, after which the data symbols are treated as sub-carrier components. The data symbols are then sent to a pilot inserter 24, where pilot symbols are inserted among the data symbols. Collectively, the data symbols and pilot symbols are referred to hereinafter simply as symbols. The symbols are passed to an Inverse Fast Fourier Transform (IFFT) processor 26, then to a multiplexer 28 where they are recombined into a serial stream. A guard inserter 30 adds prefixes to the symbols. Finally, the OFDM signals are passed through a hard limiter 32, a digital-to-analog converter 34, and a radio frequency (RF) transmitter 36 which transmits OFDM symbols as a signal through a first transmitting antenna 37. In most embodiments, each element in the first OFDM component 20 is a processor, a component of a larger processor, or a collection of processors or any suitable combination of hardware, firmware and software. These might include general purpose processors, ASICs, FPGAs, DSPs to name a few examples.

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The pilot inserter 24 is connected to receive space-time coded pilot symbols from pilot STBC function 23 which performs STBC on pilot symbols 21. The pilot STBC block 23 takes two pilot symbols at a time for example P_1 and P_2 as indicated in FIG. 2 and generates an STBC block consisting of a two by two matrix having (P_1, P_2) in the first row and having $(-P_2^*, P_1^*)$ in the second row. It is the first row of this STBC block that is inserted by the pilot inserter 24.

The data symbols sent along the second processing path 18 are sent to a second OFDM component 38 which includes processors similar to those included in the first OFDM component 20. However, the pilot inserter 40 inserts encoded pilot symbols from the second row of the STBC block produced by the pilot STBC function 23. The symbols sent along the second processing path 18 are ultimately transmitted as a signal through a second transmitting antenna 42.

Referring now to FIG. 3, a block diagram of an MIMO-OFDM receiver is shown. An OFDM receiver 50 includes a first receiving antenna 52 and a second receiving antenna 54 (although more generally there will be one or more receiving antennae). The first receiving antenna 52 receives a first received signal. The first received signal is a combination of the two signals transmitted by the two transmitting antennae 37 and 42 of FIG. 2, although each of the two signals will have been altered by a respective channel between the respective transmitting antenna and the first receiving antenna 52. The second receiving antenna 54 receives a second received signal. The second received signal is a combination of the two signals transmitted by the two transmitting antennae 37 and 42 of FIG. 2, although each of the two signals will have been altered by a respective channel between the respective transmitting antenna and the second receiving antenna 54. The four channels (between each of the two transmitting antennae and each of the two receiving antennae) may vary with time and with frequency, and will usually be different from each other.

The OFDM receiver 50 includes a first OFDM component 56 and a second OFDM component 58 (although in general there will be N OFDM components, one for each receiving antenna). The first OFDM component 56 includes a RF receiver 59, and an analog-to-digital converter 60, which converts the first received signal into digital signal samples. The signal samples are passed to a frequency synchronizer 62 and a frequency offset corrector 64. The signal samples are also fed to a frame/time synchronizer 66. Collectively, these three components produce synchronized signal samples.

The synchronized signal samples represent a time sequence of data. The synchronized signal samples are passed to a demultiplexer 68, then passed in parallel to a Fast Fourier Transform (FFT) processor 70. The FFT processor 70 performs an FFT on the signal samples to generate estimated received symbols which are multiplexed in MUX 76 and sent as received symbols to decoder 78. Ideally, the received symbols would be the same as the symbols fed into the IFFT processor 26 at the OFDM transmitter 10. However, as the received signals will have likely been altered by the various propagation channels, the first OFDM component 56 must correct the received symbols by taking into account the channels. The received symbols are passed to a channel estimator 72, which analyses received pilot symbols located at known times and frequencies within the OFDM frame. The channel estimator 72 compares the received pilot symbols with what the channel estimator 72 knows to be the values of the pilot symbols as transmitted by the OFDM transmitter 10, and generates an estimated channel response for each frequency

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and time within the OFDM symbol. The estimated channel responses are passed to decoder 78. The channel estimator 72 is described in detail below.

The second OFDM component 58 includes similar components as are included in the first OFDM component 56, and processes the second received signal in the same manner as the first OFDM component 56 processes the first received signal. Each OFDM component passes OFDM symbols to the decoder 78.

The decoder 78 applies STBC decoding to the OFDM symbols, and passes the symbols to a decoding/demodulating primitive 80 responsible for decoding, de-interleaving, and demodulating the symbols to generate output binary data, as is well known to those skilled in the art. The decoding/demodulation primitive 80 which may include a number of additional processing blocks, not shown in FIG. 2. Each element in the OFDM components 56 and 58 is a processor, a component of a larger processor, or a collection of processors.

Referring now to FIG. 4, a method by which each of the pilot inserters 24 and 40 of FIG. 2 inserts pilot symbols among the data symbols is shown. The method will be described with reference to the pilot inserter 24 in the first OFDM component 20. At step 100, the pilot inserter 24 receives data symbols from the demultiplexer 22. At step 102 the pilot STBC function 23 generates (or receives) two pilot symbols. At step 104 the pilot STBC function 23 applies STBC encoding to the pilot symbols, so as to generate an STBC block of encoded pilot symbols. The encoded pilot symbols generated for the first transmitting antenna 37 will be one row of the STBC block and will have a number equal to the number of transmitting antennae in the OFDM transmitter. Thus, for a two antenna system a 2x2 STBC block is generated.

At step 106 the pilot inserter 24 inserts the encoded pilot symbols within the OFDM symbol. Encoded pilot symbols are inserted in a diamond lattice pattern. The diamond lattice pattern uses the same frequencies as the other diamond lattice patterns, but has a temporal offset from the other diamond lattice patterns. Preferably, the temporal offset for each diamond lattice pattern is one symbol (in the time direction) from another diamond lattice pattern, so that the diamond lattice patterns use consecutive symbols in the time direction of the OFDM frame.

The diamond lattice pattern in which each encoded pilot symbol is inserted within the OFDM frame is preferably a perfect diamond lattice pattern. To achieve this, the encoded pilot symbol is inserted at each of a first subset of frequencies. The frequencies within the first subset of frequencies are spaced equally apart by a pilot spacing. The encoded pilot symbol is inserted at each of the first subset of frequencies for an STBC block (two OFDM symbols). At some later time, the encoded pilot symbols are inserted at each of a second subset of frequencies. The frequencies within the second subset of frequencies are shifted from the frequencies within the first subset of frequencies by half of the pilot spacing within the frequency direction. The pilot inserter 24 continues to insert encoded pilot symbols, alternating between the first subset of frequencies and the second subset of frequencies.

Alternatively, a different pilot pattern can be used, as long as the same pilot pattern is used for each of the at least one encoded pilot symbols unique to the transmitting antenna 37, and as long as the pilot patterns for the encoded pilot symbols are offset from each other in the time direction of the OFDM frame. For example, a regular diagonal lattice pattern may be used, the diamond shaped lattice being a special case of this.

The pilot inserter 40 inserts pilot symbols using the same method, although the pilot symbols will be the other half of

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the STBC block 42. The encoded pilot symbols unique to the second transmitting antenna 42 are inserted in the OFDM frame at the same symbol locations at which the encoded pilot symbols corresponding to the first transmitting antenna 37 are inserted.

Referring to FIG. 5, an example pilot pattern generated using the method of FIG. 4 is shown. Pilot and data symbols are spread over the OFDM frame in a time direction 120 and a frequency direction 122. Most symbols within the OFDM frame are data symbols 124. A first set of encoded pilot symbols 126 corresponding to the first transmitting antenna 37 is inserted in a diamond lattice pattern. A second set of encoded pilot symbols 128 corresponding to the first transmitting antenna 37 is inserted in a diamond lattice structure at the same frequencies as the first set of encoded pilot symbols, but offset by one OFDM symbol location in the time direction 120. In the illustrated example two of every four OFDM symbols carry encoded pilot symbols. Each other transmitting antenna transmits using the same pattern. The pairs of consecutive pilot symbols on a sub-carrier consist of two raw pilot symbols STBC encoded. The same pattern is transmitted by the second antenna.

The power of the encoded pilot symbols 126, 128 may be increased compared to the traffic data symbol 124. The power increase of the encoded pilot can be dynamically adjusted with respect to the transmitting data symbol power level or modulation type (QAM size), or as a function of channel quality. The location of diamond lattice pattern may also be optimized to allow a fast extraction of scattered pilot without using the computing. This may be achieved if the pilot sub-carriers are spaced in the frequency direction by 2^n . In the multiple base station transmission arrangement, the location of the diamond lattice pattern can be cyclic offset both in time direction and in frequency direction amongst adjacent base stations to form a diamond lattice re-use pattern.

Referring now to FIGS. 6 to 10, a channel estimation method is described which is based on the pilot insertion method above. This invention presents a simple 2-dimensional channel interpolator for MIMO-OFDM system with low pilot density for fast fading channels both in time and in frequency. The goal of channel estimation is to estimate the channel characteristics for each sub-carrier and at each time for each possible transmit antenna, receive antenna combination. Referring to FIG. 13, for the two transmit antenna, two receive antenna example, shown are two transmit antennas Tx1 140 and Tx2 142 and two receive antennas Rx1 144 and Rx2 146. Channel estimation estimates a channel for each sub-carrier and at each time between Tx1 140 and Rx1 144 indicated as each H_{11} 148, a channel between Tx1 140 and Rx2 146 indicated by transfer function H_{12} 150, a channel estimate for transmitter Tx2 142 to Rx1 144 indicated as transfer function H_{22} 152 and finally, a channel estimate for transmitter Tx2 142 to receiver Rx2 146 indicated as transfer function H_{21} 154.

Some advantages for the proposed method compared to some existing methods are: (1) robust to high mobility-speed (2) a reduction of the scattered pilot grid density and therefore a reduction of the pilot overhead.

Let P_1 and P_2 be the two pilot symbols encoded in an STBC block and transmitted by two antennas on one sub-carrier in consecutive OFDM symbols. Then at the first receive antenna, the following relationship exists for each sub-carrier on which pilot symbols are transmitted, where it is assumed the channel response H_{ij} is constant over two OFDM frames:

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$$\begin{bmatrix} Y_{1,1} \\ Y_{1,2} \end{bmatrix} = \begin{bmatrix} P_1 & P_2 \\ -P_2^* & P_1^* \end{bmatrix} \begin{bmatrix} H_{11} \\ H_{21} \end{bmatrix}$$

$Y_{1,1}$ is the received data on the first antenna on the sub-carrier in the first of the two consecutive OFDM symbols, and $Y_{1,2}$ is the received data on the first antenna on the sub-carrier in the second of the two consecutive symbols. This can be solved for H_{11} , H_{21} to yield:

$$\begin{bmatrix} H_{11} \\ H_{21} \end{bmatrix} = \frac{1}{|P_1|^2 + |P_2|^2} \begin{bmatrix} P_1^* & -P_2 \\ P_2^* & P_1 \end{bmatrix} \begin{bmatrix} Y_{1,1} \\ Y_{1,2} \end{bmatrix}$$

A similar process for the second antenna yields

$$\begin{bmatrix} H_{12} \\ H_{22} \end{bmatrix} = \frac{1}{|P_1|^2 + |P_2|^2} \begin{bmatrix} P_1^* & -P_2 \\ P_2^* & P_1 \end{bmatrix} \begin{bmatrix} Y_{2,1} \\ Y_{2,2} \end{bmatrix}$$

where $Y_{2,1}$ is the received data on the second antenna on the sub-carrier in the first of the two consecutive OFDM symbols, and $Y_{2,2}$ is the received data on the second antenna on the sub-carrier in the second of the two consecutive OFDM symbols.

Using this techniques, a channel estimate is made for each pilot sub-carrier, and for each pair of OFDM symbols used to transmit STBC blocks.

For the example of FIG. 12, the result is a channel estimate, for each of the possible channels (these are for channels in this example as shown in FIG. 13) for each pair of pilot symbols transmitted. This is illustrated in FIG. 14 where only sub-carriers used to transmit pilots are shown. A channel estimate 150 is generated for each pair of (consecutive in time) OFDM frames for each pilot sub-carrier. This results in channel estimates 150, 152, 154 for the first and second frames, and channel estimates 156, 158, 160 for the fifth and sixth frames and so on.

The channel estimates are made on a STBC block by block basis so that the pattern of channel estimate shown in FIG. 7 develops over time. The next step in the process is to perform an interpolation based on the channel estimate of FIG. 7 to obtain channel estimates for the places in FIG. 7 which do not represent pilot channel positions. The manner in which this is done will be described for a single example, namely the unknown channel estimate indicated at 163 of FIG. 7. Channel estimates are buffered on an ongoing basis and when the four channel estimates 152, 156, 158 and 164 forming a diamond 162 surrounding the unknown channel estimate 163 have been computed, it is time to interpolate to obtain a channel estimate for the unknown point 163. The channel transfer function at the sub-carrier located at the centre of the diamond can be obtained from a simple 4 points two-dimensional interpolator. Three points two-dimensional interpolators can be used to obtain the channel estimates corresponding to the first or last useful sub-carrier:

$$H_{new}(n+1, k) = \frac{1}{4}(H(n, k) + H(n+2, k) + H(n+1, k-1) + H(n+1, k+1))$$

where $(k = 2, \dots, N_{pilot} - 1)$

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-continued

$$H_{new}(n+1, 1) = \frac{1}{4}(H(n, 1) + H(n+2, 1) + 2H(n+1, 2))$$

$$H_{new}(n+1, N_{pilot}) =$$

$$\frac{1}{4}(H(n, N_{pilot}) + H(n+2, N_{pilot}) + 2H(n, N_{pilot} - 1))$$

where k is the pilot sub-carrier index, n is the channel estimate index (or STBC block number—one channel estimate per sub-carrier for every two symbols), and N_{pilot} is the number of pilot sub-carriers (6 in the example of FIG. 7). H_{new} is the newly interpolated channel estimate for the i^{th} channel estimation period, and the j^{th} pilot sub-carrier. $H(i, j)$ is the channel estimate determined as described previously from the pilot symbols. A three points interpolator would also be performed for the last STBC blocks in the OFDM frame (i.e. the last two OFDM symbols).

These calculations are done for each transmit antenna, receiver antenna combination. It is noted that this is just one example of how the channel estimates can be interpolated.

If the original distance between pilot sub-carriers in the frequency direction is D_f , after first step of interpolation described above, the pilot sub-carriers' separation becomes

$$\frac{D_f}{2}.$$

In some embodiments, to remove noise, the channel estimates thus computed are filtered at each channel estimation period. This is shown in FIG. 6 where the channel estimates 170 for one channel estimation period are shown entering filter 172 to produce filtered channel estimates. For example, a simple 3 point moving iterative smoothing algorithm may be applied to H' :

$$H'_{sm}(n, k) = H'_{sm}(n, k-1) + \frac{1}{3}(H'(n, k+1) + H'_{sm}(n, k-2))$$

where $k=3, \dots, 2N_{pilot}-2$. It is to be understood that other filtering algorithms may be employed.

After the interpolation of the pilot channel estimate as summarized in FIG. 7, there will be a channel estimate for each sub-carrier on which pilot channel information was transmitted and for each two OFDM symbol period over which pilot channeling information was transmitted. Referring to FIG. 5, this means that there will be a channel estimate for each antenna for time frequency points which are shaded to indicate that pilot channel information was transmitted. There will also be channel estimates for the time frequency point in the centre of the diamond shaped lattice structure of FIG. 7. However, for points which are not pilot symbol transmission time-frequency points nor points which are at the centre of a diamond shaped lattice of such points, there will be no channel estimate yet computed. The next step is to perform a further interpolation step to develop channel estimates for these other points.

In some embodiments, Cubic Lagrange interpolation and linear interpolation (for the sub-carriers near the first and the last useful sub-carrier) in the frequency direction are used to obtain the channel transfer function at all sub-carriers for each STBC block (for each pair of OFDM symbols).

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The coefficients of the Cubic Lagrange interpolator can be calculated as

$$\begin{aligned}\mu(i) &= \frac{i}{D_f/2} & i = 1, 2, \dots, \frac{D_f}{2} \\ q_{-1}(\mu) &= -\frac{1}{6}\mu^3 + \frac{1}{2}\mu^2 - \frac{1}{3}\mu \\ q_0(\mu) &= \frac{1}{2}\mu^3 - \mu^2 + \frac{1}{2}\mu + 1 \\ q_1(\mu) &= -\frac{1}{2}\mu^3 + \frac{1}{2}\mu^2 + \mu \\ q_2(\mu) &= -\frac{1}{6}\mu^3 - \frac{1}{6}\mu\end{aligned}$$

The channel transfer functions at data sub-carriers are given by

$$H_{interp}\left((j-1) \cdot \frac{D_f}{2} + i\right) = \sum_{n=-1}^2 q_n(\mu(i)) \cdot H'_{sm}(j+n)$$

where $j=2, \dots, N_{pilot}-2$.

This is illustrated in FIG. 9 where the estimated channel responses are fed to the Lagrange cubic interpolator 175 which outputs values for all intermediate sub-carriers. Other interpolations may alternatively be employed.

In some embodiments, every OFDM symbol contains some pilot insertion points and as such this completes the interpolation process. In other embodiments, there are some OFDM symbols which do not have any pilot insertion points. To get channel estimates for these OFDM symbols, an interpolation in time of the previously computed channel estimates is performed. In high mobility applications, pilots should be included in every OFDM symbol avoiding the need for this last interpolation in time step.

FIG. 10 presents an overall block diagram of the interpolation method proposed for two transmit antennas. An example set of performance results for the proposed MIMO-OFDM channel estimation algorithm is shown in FIG. 10. The performance of the 2-D channel estimation algorithm is close to the performance of ideal channel (only 0.5 dB loss) at very high Doppler spread.

Referring now to FIGS. 10 and 3, the channel estimation method is carried out by the channel estimator 72 in order to estimate a channel response for each sub-carrier and each OFDM symbol within an OFDM frame. The channel estimation method starts at step 500 by extracting the pilot symbols in the frequency domain for each receive antenna. This is followed by a channel response matrix computing step 502; whereby the received signal received by the receiving antenna is decoded, which in effect performs a time average of the encoded pilot symbols at each point in the pilot pattern. For example, suppose the receiving antenna receives an OFDM frame having a pilot pattern as shown in FIG. 5 (although the symbol 126 will now be a linear combination of the encoded pilot symbol transmitted at this location by each of the transmitting antenna, and the symbol 128 will be a linear combination of the encoded pilot symbol transmitted at this location by each of the transmitting antenna). Following decoding, the pilot symbol at symbol location 126 will be an average of the pilot symbol received at symbol location 126 and the pilot symbol received at symbol location 128. The time averaging effect produced by the STBC decoding, during step 503, can be viewed as a pre-processing step, as can steps 500 and 502.

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The actual channel estimation method can be described broadly in four steps. Following step 503, during step 504 the channel estimator 72 estimates the channel response for each of a plurality of pilot symbols. For a diamond lattice pattern, the plurality of pilot symbols will be four pilot symbols forming a single diamond pattern. The channel estimator 72 estimates the channel response of a central symbol, the central symbol having a time direction value and a frequency direction value bounded by the time direction values and the frequency direction values of the plurality of pilot symbols. The central symbol preferably has a frequency direction value equal to the frequency direction values of two of the plurality of pilot symbols, and has a time direction value midway between the time direction values of the two pilot symbols having the same frequency direction value as the central symbol. This can generally be described as a four-point 2-D interpolation of the channel response between pilot symbols. Third, the channel estimator 72 smoothes the channel responses (corresponding to both encoded pilot symbols and to the central symbol) in the frequency direction, preferably by performing a three-point smoothing, as per step 505. Fourth, the channel estimator 72 performs an interpolation in the frequency direction to estimate the channel response for remaining symbols, as per step 506. The interpolation may be a linear interpolation for symbols having a frequency direction value equal to a first or a last useful sub-carrier within the OFDM symbol, and a cubic Lagrange interpolation otherwise.

The method of inserting pilot symbols (described above with reference to FIG. 4) and the channel estimation method (described above with reference to FIG. 10) need not be used together. Any channel estimation method may be used by the OFDM receiver to estimate the channel responses for an OFDM frame containing encoded pilot symbols inserted using the method described above. However, due to the sparse distribution of the pilot symbols in the pilot pattern described above with reference to FIG. 4 and FIG. 5, a two-dimensional interpolation method is preferable over a one-dimensional interpolation method. Similarly, the channel estimation method may be applied to an OFDM frame containing any pattern of pilot symbols.

The invention has been described with respect to an MIMO-OFDM communication system. The invention may also be used with advantage in a single input-multiple output OFDM communication system, as the method of inserting pilot symbols (described with reference to FIG. 4) and the channel estimation method (described with reference to FIG. 10) do not depend on the number of receiving antenna. Each receiving antenna within the OFDM receiver 50 performs channel estimation independently, regardless of the number of receiving antennae present.

The channel estimation method described with reference to FIG. 10 will also be advantageous in an OFDM communication system having only one transmitting antenna, as the method provides an improved interpolation of the channel response regardless of the number of transmitting antenna. The method of inserting pilot symbols described with reference to FIG. 11 may be used in an OFDM communication system having only one transmitting antenna, but will not be as advantageous as in an OFDM communication system having more than one transmitting antenna as there will be no reduction in overhead.

The method of inserting pilot symbols and the channel estimation method are preferably implemented on the OFDM transmitter and on the OFDM receiver respectively in the form of software instructions readable by a digital signal processor. Alternatively, the methods may be implemented as

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logic circuitry within an integrated circuit. More generally, any computing apparatus containing logic for executing the described functionality may implement the methods. The computing apparatus which implements the methods (in particular the pilot inserter or the channel estimator) may be a single processor, more than one processor, or a component of a larger processor. The logic may comprise external instructions stored on a computer-readable medium, or may comprise internal circuitry.

What has been described is merely illustrative of the application of the principles of the invention. Other arrangements and methods can be implemented by those skilled in the art without departing from the spirit and scope of the present invention.

We claim:

1. A method of transmitting symbols using Orthogonal Frequency Division Multiplexing, OFDM, frames at an OFDM transmitter having at least two transmitting antennas, the OFDM frames having a time domain and a frequency domain, each OFDM frame comprising a plurality of OFDM symbols in the time domain, and a plurality of sub-carriers in the frequency domain, the method comprising the steps of:

transmitting, on an OFDM symbol, pilot symbols corresponding to the first antenna using a scattered pattern; and

transmitting, on the OFDM symbol, pilot symbols corresponding to the second antenna using the scattered pattern, wherein the pilot symbols for the first antenna correspond to a first code and the pilot symbols for the second antenna correspond to a second code.

2. The method of claim 1, further comprising transmitting the pilot symbols with a power level which is dynamically adjusted as a function of a modulation type applied to the sub-carriers carrying data.

3. The method of claim 1, wherein the first and second codes are space time block codes.

4. The method of claim 1, further comprising applying an inverse fast Fourier transform to the pilot symbols.

5. The method of claim 1, wherein the scattered pattern is a diamond lattice pattern.

6. The method of claim 1, further comprising transmitting data symbols from the first and second antenna of the OFDM transmitter.

7. The method of claim 1, wherein the scattered pattern is scattered in time and frequency.

8. The method of claim 1, wherein each OFDM frame includes a preamble.

9. A device for transmitting pilot symbols using Orthogonal Frequency Division Multiplexing, OFDM, frames at an OFDM transmitter having at least two transmitting antennas, the OFDM frames having a time domain and a frequency domain, each OFDM frame comprising a plurality of OFDM symbols in the time domain, and a plurality of sub-carriers in the frequency domain, comprising:

a first antenna of the OFDM transmitter;

a second antenna of the OFDM transmitter; and

one or more processors configured to:

cause transmission via the first antenna, on an OFDM symbol, pilot symbols corresponding to the first antenna using a scattered pattern; and

cause transmission via the second antenna, on the OFDM symbol, pilot symbols corresponding to the second antenna using the scattered pattern, wherein the pilot symbols for the first antenna correspond to a first code and the pilot symbols for the second antenna correspond to a second code.

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10. The device of claim 9, the one or more processors further configured to cause transmission of the pilot symbols with a power level which is dynamically adjusted as a function of a modulation type applied to the sub-carriers carrying data.

11. The device of claim 9, wherein the first and second codes are space time block codes.

12. The device of claim 9, the one or more processors further configured to apply an inverse fast Fourier transform to the pilot symbols.

13. The device of claim 9, wherein the scattered pattern is a diamond lattice pattern.

14. The device of claim 9, the one or more processors further configured to cause transmission of data symbols from the first and second antenna of the OFDM transmitter.

15. The device of claim 9, wherein the scattered pattern is scattered in time and frequency.

16. The device of claim 9, wherein each OFDM frame includes a preamble.

17. A non-transitory computer readable medium for transmitting symbols using Orthogonal Frequency Division Multiplexing, OFDM, frames at an OFDM transmitter having at least two transmitting antennas, the OFDM frames having a time domain and a frequency domain, each OFDM frame comprising a plurality of OFDM symbols in the time domain and a plurality of sub-carriers in the frequency domain, the computer readable medium storing instructions to cause a processor to perform operations comprising:

transmitting, on an OFDM symbol, pilot symbols corresponding to the first antenna using a scattered pattern; and

transmitting, on the OFDM symbol, pilot symbols corresponding to the second antenna using the scattered pattern, wherein the pilot symbols for the first antenna correspond to a first code and the pilot symbols for the second antenna correspond to a second code.

18. The computer readable medium of claim 17, the operations further comprising transmitting the pilot symbols with a power level which is dynamically adjusted as a function of a modulation type applied to the sub-carriers carrying data.

19. The computer readable medium of claim 17, wherein the first and second codes are space time block codes.

20. The computer readable medium of claim 17, the operations further comprising applying an inverse fast Fourier transform to the pilot symbols.

21. The computer readable medium of claim 17, wherein the scattered pattern is a diamond lattice pattern.

22. The computer readable medium of claim 17, the operations further comprising transmitting data symbols from the first and second antenna of the OFDM transmitter.

23. The computer readable medium of claim 17, wherein the scattered pattern is scattered in time and frequency.

24. The computer readable medium of claim 17, wherein each OFDM frame includes a preamble.

25. A method for receiving symbols using Orthogonal Frequency Division Multiplexing, OFDM, frames transmitted from an OFDM transmitter having at least two transmitting antennas, the OFDM frames having a time domain and a frequency domain, each OFDM frame comprising a plurality of OFDM symbols in the time domain and a plurality of sub-carriers in the frequency domain, the method comprising the steps of:

receiving, on an OFDM symbol, pilot symbols corresponding to the first antenna using a scattered pattern; and

receiving, on the OFDM symbol, pilot symbols corresponding to the second antenna using the scattered pattern, wherein the pilot symbols for the first antenna

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correspond to a first code and the pilot symbols for the second antenna correspond to a second code.

26. The method of claim 25, further comprising receiving the pilot symbols with a power level which is dynamically adjusted as a function of a modulation type applied to the sub-carriers carrying data.

27. The method of claim 25, wherein the first and second codes are space time block codes.

28. The method of claim 25, further comprising estimating a channel based on the received pilot symbols.

29. The method of claim 25, wherein the scattered pattern is a diamond lattice pattern.

30. The method of claim 25, further comprising receiving data symbols from the first and second antenna of the OFDM transmitter.

31. A User Equipment (UE) for receiving pilot symbols using Orthogonal Frequency Division Multiplexing, OFDM, frames transmitted from an OFDM transmitter having at least two transmitting antennas, the OFDM frames having a time domain and a frequency domain, each OFDM frame comprising a plurality of OFDM symbols in the time domain and a plurality of sub-carriers in the frequency domain, comprising: a receiver configured to:

receive, on an OFDM symbol, pilot symbols corresponding to the first antenna using a scattered pattern; and

receive, on the OFDM symbol, pilot symbols corresponding to the second antenna using the scattered pattern, wherein the pilot symbols for the first antenna correspond to a first code and the pilot symbols for the second antenna correspond to a second code.

32. The device of claim 31, the receiver further configured to receive the pilot symbols with a power level which is dynamically adjusted as a function of a modulation type applied to the sub-carriers carrying data.

33. The device of claim 31, wherein the first and second codes are space time block codes.

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34. The device of claim 31, the UE further comprises a processor configured to estimate a channel based on the received pilot symbols.

35. The device of claim 31, wherein the scattered pattern is a diamond lattice pattern.

36. The device of claim 31, the receiver further configured to transmit data symbols from the first and second antenna of the OFDM transmitter.

37. A non-transitory computer readable medium for receiving symbols using Orthogonal Frequency Division Multiplexing, OFDM, frames transmitted from an OFDM transmitter having at least two transmitting antennas, the OFDM frames having a time domain and a frequency domain, each OFDM frame comprising a plurality of OFDM symbols in the time domain and a plurality of sub-carriers in the frequency domain, the computer readable medium storing instructions to cause a processor to perform operations comprising:

receiving, on an OFDM symbol, pilot symbols corresponding to the first antenna using a scattered pattern; and receiving, on the OFDM symbol, pilot symbols corresponding to the second antenna using the scattered pattern, wherein the pilot symbols for the first antenna correspond to a first code and the pilot symbols for the second antenna correspond to a second code.

38. The computer readable medium of claim 37, the operations further comprising receiving the pilot symbols with a power level which is dynamically adjusted as a function of a modulation type applied to the sub-carriers carrying data.

39. The computer readable medium of claim 37, wherein the first and second codes are space time block codes.

40. The computer readable medium of claim 37, the operations further comprising estimating a channel based on the received pilot symbols.

41. The computer readable medium of claim 37, wherein the scattered pattern is a diamond lattice pattern.

42. The computer readable medium of claim 37, the instructions further comprising receiving data symbols from the first and second antenna of the OFDM transmitter.

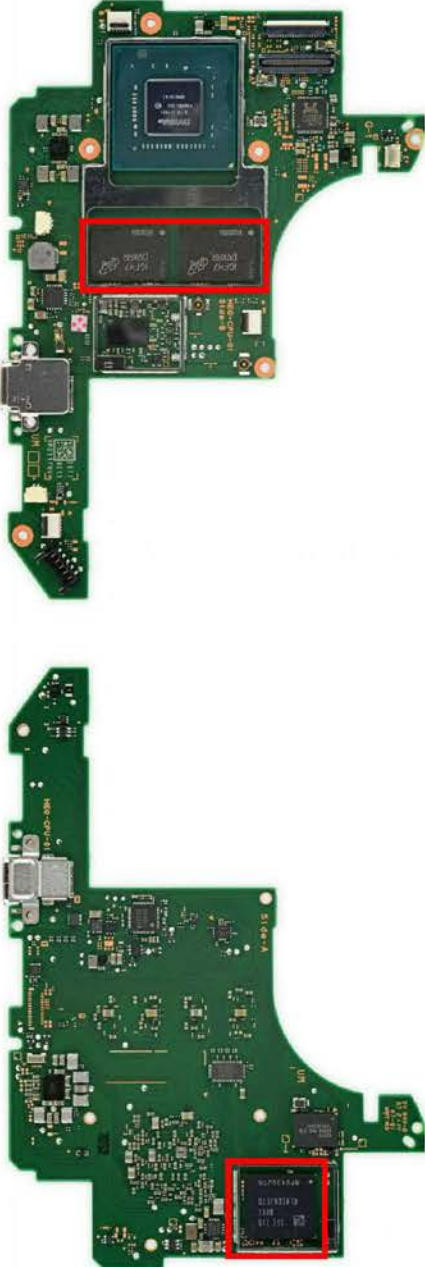
* * * * *

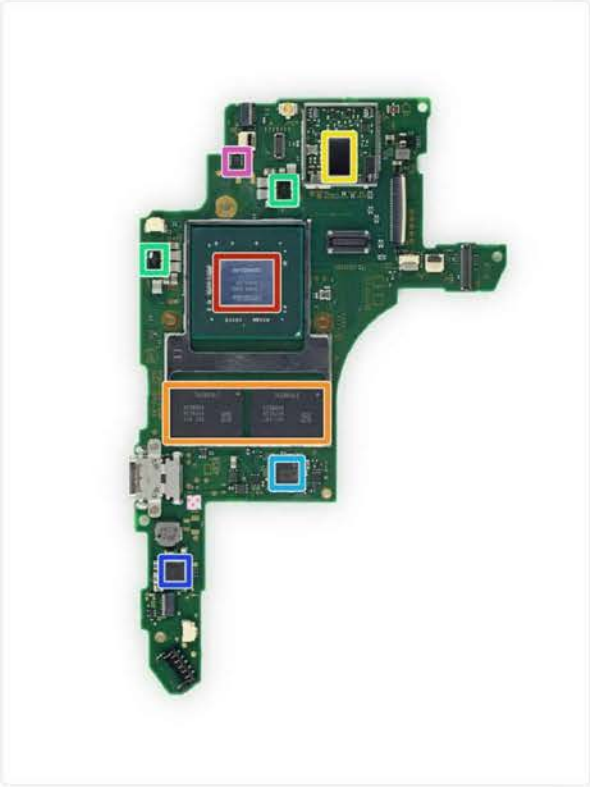
EXHIBIT G

Exhibit G – U.S. Patent No. 9,542,571

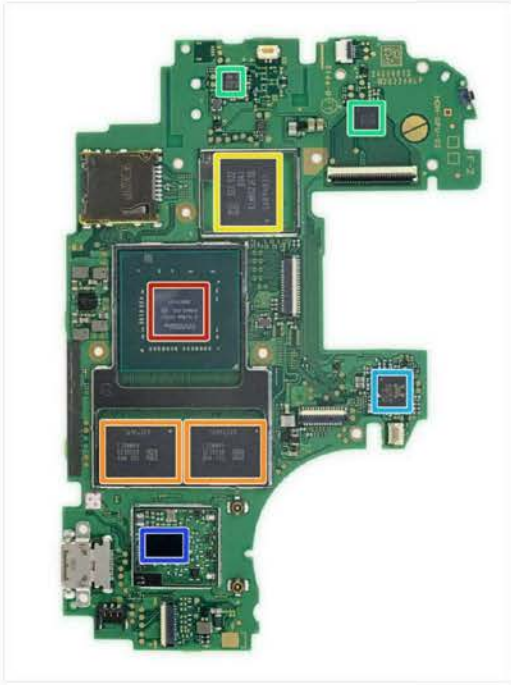
Claims	Identification
10[pre]: A device, comprising:	To the extent the preamble is limiting, Nintendo-branded devices are devices comprising the following limitations. General information The parental controls for Nintendo Switch allow you to manage which features and games your child can use on their system. Setting up parental controls allows you to set restrictions through the Nintendo Switch console or with the more extensive Nintendo Switch Parental Controls smart device app. You can also set restrictions for Nintendo eShop through your Nintendo Account. • Parental controls can restrict the download and use of certain content, set play time limits, and restrict the use of certain features on Nintendo Switch. • Parental controls are set for the system - not the user. Once set, the same restrictions will be in place for everyone that uses the system. • The parent/guardian chooses a PIN number (between 4 and 8 digits long) when setting up the parental controls. The PIN will be used in the future whenever a restriction needs to be bypassed or changed. • Parental controls can also be managed on your smart device, via the Nintendo Switch Parental Controls application. Some features (such as play time limits) can only be managed through the smart device application. Please note that an Internet connection is required to use this feature. See, e.g., <i>Parental Controls Overview/FAQ (Nintendo Switch)</i>, Nintendo, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22508.

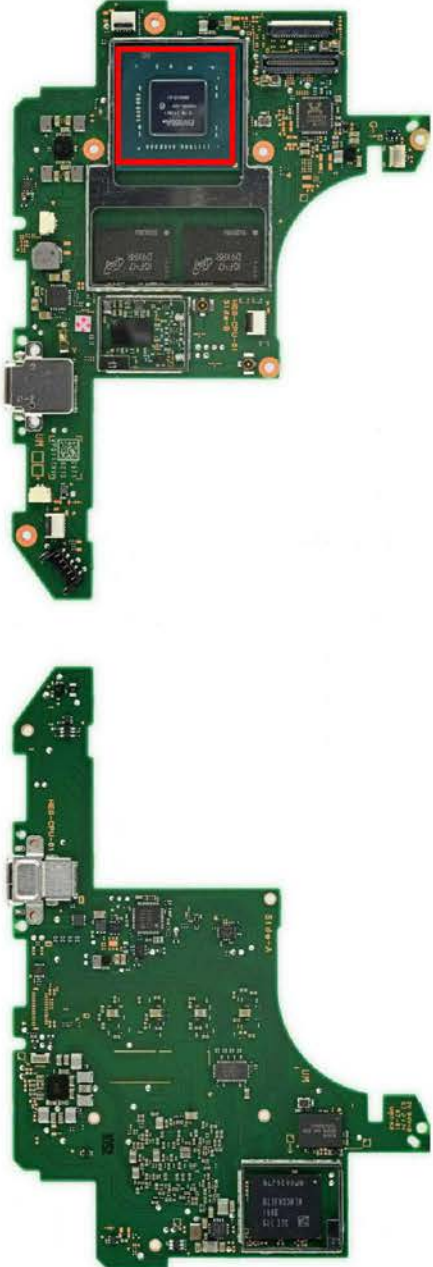
Claims	Identification		
	 Nintendo Switch Parental Controls mobile app Set gaming guidelines for the family right from your smart device with this free app. Download on the App Store GET IT ON Google Play It's only natural for parents to have questions about their kids and gaming. • How much time does my family spend gaming? • Are the games appropriate for my family? • How can I set limits on what they can do online with the system? That's why Nintendo Switch has parental controls that let you set rules for using the system—so you can spend less time worrying and more time having fun. While some parental controls are available on the system itself, the free app gives you even more options. See, e.g., <i>Nintendo Switch Parental Controls mobile app</i>, Nintendo, https://www.nintendo.com/us/switch/parental-controls/; <i>Parental Controls Overview/FAQ (Nintendo Switch)</i>, Nintendo Customer Support, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22508; <i>How to Set Up, Adjust, or Remove Nintendo Switch Parental Controls</i>, Nintendo Customer Support, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22447; <i>Nintendo Switch™</i>, Entertainment Software Rating Board, https://www.esrb.org/tools-for-parents/parental-controls/nintendo-switch/. 		
10[b] a memory; and	Nintendo-branded devices include a memory. Nintendo Switch™ - OLED Model <table border="1"> <tr> <td>CPU/GPU</td> <td>NVIDIA Custom Tegra processor</td> </tr> </table>	CPU/GPU	NVIDIA Custom Tegra processor
CPU/GPU	NVIDIA Custom Tegra processor		

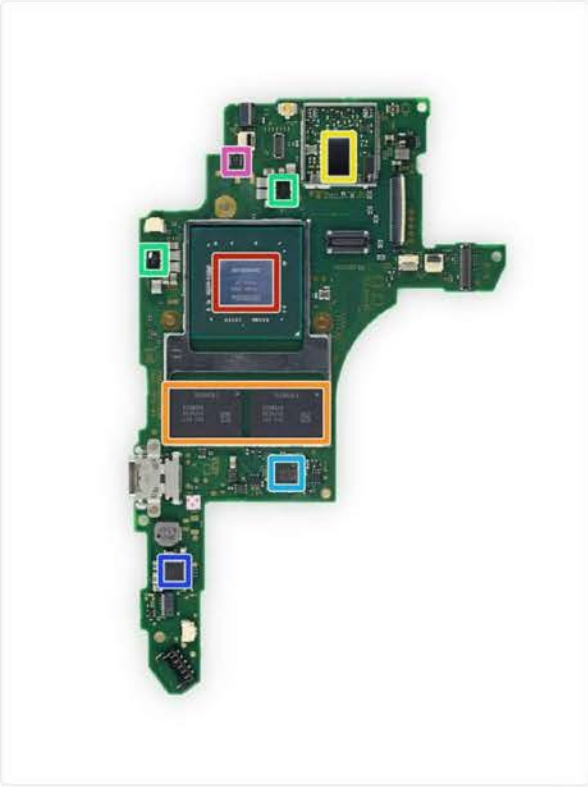
Claims	Identification				
	 [...] <table><tr><td>CPU/GPU</td><td>NVIDIA Custom Tegra processor</td></tr></table>  [...] <table><tr><td>CPU/GPU</td><td>NVIDIA Custom Tegra processor</td></tr></table>	CPU/GPU	NVIDIA Custom Tegra processor	CPU/GPU	NVIDIA Custom Tegra processor
CPU/GPU	NVIDIA Custom Tegra processor				
CPU/GPU	NVIDIA Custom Tegra processor				
	See, e.g., <i>Nintendo Switch Technical Specs</i>, Nintendo, https://www.nintendo.com/us/switch/tech-specs/.  Silicon-wise, we see a lot of similarities to Switches past, with the main differences being: • Accelerometer made by TDK-Invensense instead of STMicroelectronics • LPDDR4 Memory made by Micron instead of Samsung • NAND Flash made by Samsug instead of Toshiba				

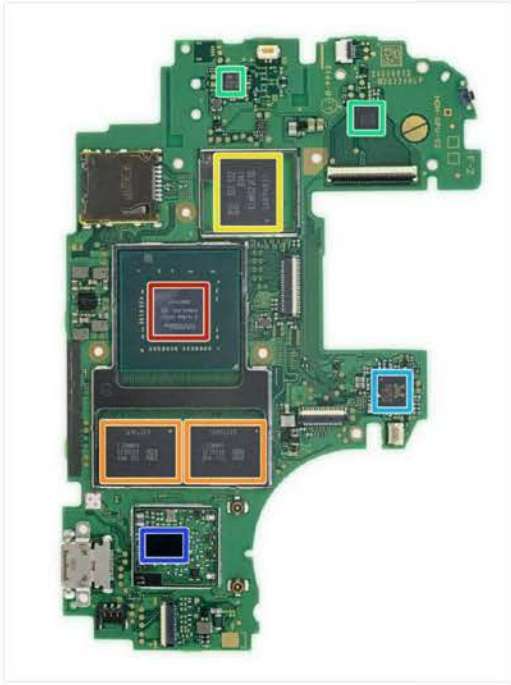
Claims	Identification
	See, e.g., Sam Goldheart, <i>Nintendo Switch OLED Teardown: More Than Screen Deep</i>, IFIXIT (Oct. 13, 2021), https://www.ifixit.com/News/53272/nintendo-switch-oled-teardown-more-than-screen-deep. Step 11  • A small gathering of ~~Mis~~ ICs populates the front side of the motherboard: • NVIDIA ODNX02-A2 (presumably the Tegra X1-based SoC) • Samsung K4F6E304HB-MGCH 2 GB LPDDR4 DRAM (x2 for a total of 4 GB) • Broadcom/Cypress BCM4356 802.11ac 2x2 + Bluetooth 4.1 SoC • Maxim Integrated MAX77621AEWI+T three phase buck regulator (x2) • Rohm BM92T36 USB-C controller • Texas Instruments BQ24193 single cell battery charger (possibly) • Texas Instruments TMP451 remote/local temperature sensor

Claims	Identification
	Step 10   • This is a well-connected motherboard; to get it free, we pop off the digitizer, backlight, and speaker connectors, two antennas, and the two Joy-Con rails. And then remove six Phillips screws. • But hey, that's some awesome modularity. Even the eMMC storage pops off with an independent PCB! • Nintendo made a 6.2" tablet with removable flash storage, so don't say it can't be done. • The storage board contains a single Toshiba THGBMH8C2LBAIL 32 GB eMMC NAND Flash IC. • Sadly, the modularity ends at the USB-C port. This high-wear component will require some intense soldering skills to replace. See, e.g., Evan Noronha et al., <i>Nintendo Switch Teardown</i>, IFIXIT (Mar. 3, 2017), https://www.ifixit.com/Teardown/Nintendo+Switch+Teardown/78263.

Claims	Identification		
	Step 8  • Removing the board, we note that the formerly modular flash storage is also now soldered down. (DIY storage swaps in the original Switch didn't work, but were at least physically possible.) • Side A of this silicon copybara: • Nvidia ODNX10-A1 (Tegra X1-based SoC, presumably a custom riff on the T210B01 variant) • 2x Samsung K4U6E3S4AM-MGCJ LPDDR4X DRAM 16 Gb (4 GB total) • Samsung KLM8G2JTD-B041 32 GB eMMC flash storage • ST Microelectronics ST21NFCD NFC controller and FingerTip touch screen controller • Realtek ALC5639 audio codec • Cypress CYW4356X 802.11ac Wi-Fi + Bluetooth 5.0 SoC See, e.g., Jeff Suovanen et al., <i>Nintendo Switch Lite Teardown</i>, IFIXIT (Sept. 24, 2019), https://www.ifixit.com/Teardown/Nintendo+Switch+Lite+Teardown/126223. Nintendo-branded devices include a processor coupled with the memory and configured by instructions stored in the memory to perform the following steps. Nintendo Switch™ - OLED Model  [...] <table><tr><td>Storage</td><td>64 GB Users can easily expand storage space using microSDHC or microSDXC cards up to 2TB (sold separately).</td></tr></table>	Storage	64 GB Users can easily expand storage space using microSDHC or microSDXC cards up to 2TB (sold separately).
Storage	64 GB Users can easily expand storage space using microSDHC or microSDXC cards up to 2TB (sold separately).		
10[b] a processor coupled with the memory and configured by instructions stored in the memory to:			

Claims	Identification
	 [...] Nintendo Switch™ console (HAC-001(-01)) Storage 32 GB of internal storage, a portion of which is reserved for use by the system. Users can easily expand storage space using microSDHC or microSDXC cards up to 2TB (sold separately).  [...] Nintendo Switch Lite (HDH-001) Storage 32 GB of internal storage, a portion of which is reserved for use by the system. Users can easily expand storage space using microSDHC or microSDXC cards up to 2TB (sold separately).
	See, e.g., <i>Nintendo Switch Technical Specs</i>, Nintendo, https://www.nintendo.com/us/switch/tech-specs/.  See, e.g., Sam Goldheart, <i>Nintendo Switch OLED Teardown: More Than Screen Deep</i>, IFIXIT (Oct. 13, 2021), https://www.ifixit.com/News/53272/nintendo-switch-oled-teardown-more-than-screen-deep.

Claims	Identification
	Step 11  • A small gathering of ~~Miss~~ ICs populates the front side of the motherboard: • NVIDIA ODNX02-A2 (presumably the Tegra X1-based SoC) • Samsung K4F6E304HB-MGCH 2 GB LPDDR4 DRAM (x2 for a total of 4 GB) • Broadcom/Cypress BCM4356 802.11ac 2x2 + Bluetooth 4.1 SoC • Maxim Integrated MAX77621AEWI+T three phase buck regulator (x2) • Rohm BM92T36 USB-C controller • Texas Instruments BQ24193 single cell battery charger (possibly) • Texas Instruments TMP451 remote/local temperature sensor See, e.g., Evan Noronha et al., <i>Nintendo Switch Teardown</i>, IFIXIT (Mar. 3, 2017), https://www.ifixit.com/Teardown/Nintendo+Switch+Teardown/78263.

Claims	Identification
	Step 8  • Removing the board, we note that the formerly modular flash storage is also now soldered down. (DIY storage swaps in the original Switch didn't work, but were at least physically possible.) • Side A of this silicon copybara: • Nvidia ODNX10-A1 (Tegra X1-based SoC, presumably a custom riff on the T210B01 variant) • 2x Samsung K4U6E3S4AM-MGCJ LPDDR4X DRAM 16 Gb (4 GB total) • Samsung K1MBG2JTD-B041 32 GB eMMC flash storage • ST Microelectronics ST21NFCD NFC controller and FingerTip touch screen controller • Realtek ALC5639 audio codec • Cypress CYW4356X 802.11ac Wi-Fi + Bluetooth 5.0 SoC See, e.g., Jeff Suovanen et al., <i>Nintendo Switch Lite Teardown</i>, IFIXIT (Sept. 24, 2019), https://www.ifixit.com/Teardown/Nintendo+Switch+Lite+Teardown/126223. Nintendo-branded devices receive owner information from an owner of the device.
10[c]: receive owner information from an owner of the device;	Forgot Parental Controls PIN on Nintendo Switch Parental controls can be set directly on the Nintendo Switch system or through the Nintendo Switch Parental Controls app for smart devices. The person who initially sets the parental controls selects a 4-8 digit PIN number, which is required to adjust or change settings in the future. Applies to: Nintendo Switch Family, Nintendo Switch Online Follow these steps to locate or reset the parental controls PIN  for Nintendo Switch.

Claims	Identification
	See, e.g., <i>Forgot Parental Controls PIN on Nintendo Switch</i>, Nintendo, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22299/. General information The parental controls for Nintendo Switch allow you to manage which features and games your child can use on their system. <u>Setting up parental controls</u> allows you to set restrictions through the Nintendo Switch console or with the more extensive Nintendo Switch Parental Controls smart device app. You can also set <u>restrictions for Nintendo eShop</u> through your Nintendo Account. • Parental controls can restrict the download and use of certain content, set play time limits, and restrict the use of certain features on Nintendo Switch. • Parental controls are set for the system - not the user. Once set, the same restrictions will be in place for everyone that uses the system. • The parent/guardian chooses a PIN number (between 4 and 8 digits long) when setting up the parental controls. The PIN will be used in the future whenever a restriction needs to be bypassed or changed. • Parental controls can also be managed on your smart device, via the <u>Nintendo Switch Parental Controls</u> application. Some features (such as play time limits) can only be managed through the smart device application. Please note that an Internet connection is required to use this feature. See, e.g., <i>Parental Controls Overview/FAQ (Nintendo Switch)</i>, Nintendo, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22508/.

Claims	Identification
	Complete these steps 1. <u>Log in</u> to your existing parent/guardian Nintendo Account to access your Nintendo Account settings. • Only a parent/guardian Nintendo Account in a Nintendo family group can set Nintendo eShop purchase restrictions. 2. Click Family group to see a list of all supervised accounts (?) in the family group. 3. Click the Nintendo Account where you want to manage restrictions. 4. Click each setting that you want to adjust: • Spending/purchases on Nintendo Switch eShop and nintendo.com Check the box to disable purchases and auto-renewal options on Nintendo Switch AND through the My Nintendo Store (including physical orders). • Viewing of content on Nintendo Switch eShop Check Restrict to restrict the content that can be seen on the Nintendo eShop on Nintendo Switch. Content will automatically be restricted based on the player's age. 5. Click Save changes to confirm the change. See, e.g., <i>How to Set Nintendo eShop Restrictions</i>, Nintendo, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22444.

Claims	Identification
10[d]: receive owner control information that comprises: a list of applications permitted for installation on the device, and permissions associated with each permitted application in the list of applications;	Nintendo-branded devices receive owner control information that comprises a list of applications permitted for installation on the electronic device, and permissions associated with each permitted application in the list of applications.  The advertisement for the Nintendo Switch Parental Controls mobile app features the Nintendo Switch logo on the left. The main text reads: 'Set gaming guidelines for the family right from your smart device with this free app.' Below this text are icons for the App Store and Google Play. On the right side of the ad is a photograph of a woman and two children sitting together, with the woman holding a Nintendo Switch console. It's only natural for parents to have questions about their kids and gaming. • How much time does my family spend gaming? • Are the games appropriate for my family? • How can I set limits on what they can do online with the system? That's why Nintendo Switch has parental controls that let you set rules for using the system—so you can spend less time worrying and more time having fun. While some parental controls are available on the system itself, the free app gives you even more options. See, e.g., <i>Nintendo Switch Parental Controls mobile app</i>, Nintendo, https://www.nintendo.com/us/switch/parental-controls/; <i>Parental Controls Overview/FAQ (Nintendo Switch)</i>, Nintendo Customer Support, https://en-americas-support.nintendo.com/app/answers/detail/a_id/225508; How to Set Up, Adjust, or Remove Nintendo Switch Parental Controls, Nintendo Customer Support, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22447; Nintendo Switch™, Entertainment Software Rating Board, https://www.esrb.org/tools-for-parents/parental-controls/nintendo-switch/.  The screenshot shows the 'Restriction Level' screen of the app. It has a dropdown menu currently set to 'None'. Below the menu are options for 'Teen', 'Pre-Teen', 'Child', and 'Custom Settings'. A note states: 'This will restrict gameplay and other features as appropriate for the child playing the Nintendo Switch console.' Under 'Custom Settings', there are three expandable sections: 'Restricted Software' (with a note 'Games rated for ages 6+ / ESRB (USA & Canada)'), 'Communicating with Others' (marked 'Not Restricted'), and 'Posting to Social Media' (marked 'Restricted'). At the bottom, it says 'Confirm your settings. Use Custom Settings to take your options.'

Claims	Identification																																								
	General information The parental controls for Nintendo Switch allow you to manage which features and games your child can use on their system. Setting up parental controls allows you to set restrictions through the Nintendo Switch console or with the more extensive Nintendo Switch Parental Controls smart device app. You can also set restrictions for Nintendo eShop through your Nintendo Account. Parental controls can restrict the download and use of certain content, set play time limits, and restrict the use of certain features on Nintendo Switch. Features and settings that can be restricted through Parental Controls <table><tr><th>Categories</th><th>Nintendo Switch system</th><th>Smart device app</th><th>Nintendo Account</th></tr><tr><td>Software by age rating</td><td>✓</td><td>✓</td><td>⌀</td></tr><tr><td>Posting to social media</td><td>✓</td><td>✓</td><td>⌀</td></tr><tr><td>Communication with others</td><td>✓</td><td>✓</td><td>⌀</td></tr><tr><td>VR Mode (3D Visuals)</td><td>✓</td><td>✓</td><td>⌀</td></tr><tr><td>Play-time limits</td><td>⌀</td><td>✓</td><td>⌀</td></tr><tr><td>View play activity</td><td>⌀</td><td>✓</td><td>⌀</td></tr><tr><td>Purchase restrictions</td><td>⌀</td><td>⌀</td><td>✓</td></tr><tr><td>Disable Friend Suggestions</td><td>⌀</td><td>⌀</td><td>✓</td></tr><tr><td>Manage info shared with 3rd parties</td><td>⌀</td><td>⌀</td><td>✓</td></tr></table>	Categories	Nintendo Switch system	Smart device app	Nintendo Account	Software by age rating	✓	✓	⌀	Posting to social media	✓	✓	⌀	Communication with others	✓	✓	⌀	VR Mode (3D Visuals)	✓	✓	⌀	Play-time limits	⌀	✓	⌀	View play activity	⌀	✓	⌀	Purchase restrictions	⌀	⌀	✓	Disable Friend Suggestions	⌀	⌀	✓	Manage info shared with 3rd parties	⌀	⌀	✓
Categories	Nintendo Switch system	Smart device app	Nintendo Account																																						
Software by age rating	✓	✓	⌀																																						
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Communication with others	✓	✓	⌀																																						
VR Mode (3D Visuals)	✓	✓	⌀																																						
Play-time limits	⌀	✓	⌀																																						
View play activity	⌀	✓	⌀																																						
Purchase restrictions	⌀	⌀	✓																																						
Disable Friend Suggestions	⌀	⌀	✓																																						
Manage info shared with 3rd parties	⌀	⌀	✓																																						

Malikie Innovations Ltd. et al. v. Nintendo Co. Ltd. et al
Exhibit G – U.S. Patent No. 9,542,571

Claims	Identification
	What are the preset parental control restriction levels on Nintendo Switch? When setting up parental controls for Nintendo Switch, you can choose from the following preset restriction levels (or customize the restrictions yourself). Teen • Restricted Software - Games rated for ages 17+ (games rated Mature by the ESRB) • Posting to Social Media - Not Restricted • Communicating with Others - Not Restricted • Software Rating Organization - Appropriate organization for your region • VR Mode (3D Visuals) - Not Restricted Pre-Teen • Restricted Software - Games rated for ages 13+ (games rated Teen and Mature by the ESRB) • Posting to Social Media - Restricted • Communicating with Others - Restricted • Software Rating Organization - Appropriate organization for your region • VR Mode (3D Visuals) - Not Restricted Child • Restricted Software - Games rated for ages 8+ (games rated Everyone 10+, Teen and Mature by the ESRB) • Posting to Social Media - Restricted • Communicating with Others - Restricted • Software Rating Organization - Appropriate organization for your region • VR Mode (3D Visuals) - Restricted See, e.g., <i>Parental Controls Overview/FAQ (Nintendo Switch)</i>, Nintendo, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22508.

Claims	Identification
	Complete these steps 1. Log in to your existing parent/guardian Nintendo Account to access your Nintendo Account settings. • Only a parent/guardian Nintendo Account in a Nintendo family group can set Nintendo eShop purchase restrictions. 2. Click Family group to see a list of all supervised accounts (?) in the family group. 3. Click the Nintendo Account where you want to manage restrictions. 4. Click each setting that you want to adjust: • Spending/purchases on Nintendo Switch eShop and nintendo.com Check the box to disable purchases and auto-renewal options on Nintendo Switch AND through the My Nintendo Store (including physical orders). • Viewing of content on Nintendo Switch eShop Check Restrict to restrict the content that can be seen on the Nintendo eShop on Nintendo Switch. Content will automatically be restricted based on the player's age. 5. Click Save changes to confirm the change. See, e.g., <i>How to Set Nintendo eShop Restrictions</i>, Nintendo, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22444.

Claims	Identification
	The main parental controls screen on your app gives you access to many different options, including: 1. "Play-Time Limits" can be set to notify the user if they have exceeded the daily play-time limit. These settings can be set individually by day. - o "Play-Time Limit" – restricts the amount of time spent playing games. When the allotted time is up the console will not automatically turn off, but you will have the option to turn off the game remotely via the "Suspend Software" option in the Time Limits window in the app. - o "Bedtime Alarm" – allows you to notify your children of when it's time to turn off the console for the evening. 2. "Restriction Level" based on the following parameters: Teen, Pre-Teen, Child, Custom. Selecting "Custom" will allow you to make granular decisions about the content your children will have access to on the Nintendo Switch console: 3. "Restricted Software" – allows you to restrict titles based on the age of your children up to 18+. This will translate to the ESRB rating parameters. For example, if you select 13+, your console will have access to games rated EC (Early Childhood), E (Everyone), E10+ (Everyone 10+) and T (Teen). Playing of captured videos in the Album will follow the same restriction. 4. "Communicating with Others" – allows you to restrict or limit the ability to interact with other players online. This can be set on a game-by-game basis. 5. "Posting Screenshots on Social Networks" – allows you to restrict the ability to post screenshots to social networks like Twitter and Facebook. 6. "Whitelist" – allows you to add specific software titles to the whitelist to exclude them from some Parental Controls restrictions on the Nintendo Switch console. See, e.g., <i>Nintendo Switch</i>™, Entertainment Software Rating Board, https://www.esrb.org/tools-for-parents/parental-controls/nintendo-switch/.

Claims	Identification
10[e]: store the owner control information in a protected data store to prevent alteration or deletion of the owner control information in response to authenticating the owner control information using the owner information;	Nintendo-branded devices, on information and belief, store the owner control information in a protected data store to prevent alteration or deletion of the owner control information in response to authenticating the owner control information using the owner information; Forgot Parental Controls PIN on Nintendo Switch Parental controls can be set directly on the Nintendo Switch system or through the Nintendo Switch Parental Controls app for smart devices. The person who initially sets the parental controls selects a 4-8 digit PIN number, which is required to adjust or change settings in the future. Applies to: Nintendo Switch Family, Nintendo Switch Online, and Nintendo Switch Online + Nintendo Switch Online Individual Follow these steps to locate or reset the parental controls PIN  for Nintendo Switch. See, e.g., Forgot Parental Controls PIN on Nintendo Switch, Nintendo, https://en-america-support.nintendo.com/app/answers/detail/a_id/22299/.

Malikie Innovations Ltd. et al. v. Nintendo Co. Ltd. et al
Exhibit G – U.S. Patent No. 9,542,571

Claims	Identification
	General information The parental controls for Nintendo Switch allow you to manage which features and games your child can use on their system. <u>Setting up parental controls</u> allows you to set restrictions through the Nintendo Switch console or with the more extensive Nintendo Switch Parental Controls smart device app. You can also <u>set restrictions for Nintendo eShop</u> through your Nintendo Account. • Parental controls can restrict the download and use of certain content, set play time limits, and restrict the use of certain features on Nintendo Switch. • Parental controls are set for the system - not the user. Once set, the same restrictions will be in place for everyone that uses the system. • The parent/guardian chooses a PIN number (between 4 and 8 digits long) when setting up the parental controls. The PIN will be used in the future whenever a restriction needs to be bypassed or changed. • Parental controls can also be managed on your smart device, via the <u>Nintendo Switch Parental Controls</u> application. Some features (such as play time limits) can only be managed through the smart device application. Please note that an Internet connection is required to use this feature.

Claims	Identification																																								
	Features and settings that can be restricted through Parental Controls <table><tr><th>Categories</th><th>Nintendo Switch system</th><th>Smart device app</th><th>Nintendo Account</th></tr><tr><td>Software by age rating</td><td>✓</td><td>✓</td><td>⌀</td></tr><tr><td>Posting to social media</td><td>✓</td><td>✓</td><td>⌀</td></tr><tr><td>Communication with others</td><td>✓</td><td>✓</td><td>⌀</td></tr><tr><td>VR Mode (3D Visuals)</td><td>✓</td><td>✓</td><td>⌀</td></tr><tr><td>Play-time limits</td><td>⌀</td><td>✓</td><td>⌀</td></tr><tr><td>View play activity</td><td>⌀</td><td>✓</td><td>⌀</td></tr><tr><td>Purchase restrictions</td><td>⌀</td><td>⌀</td><td>✓</td></tr><tr><td>Disable Friend Suggestions</td><td>⌀</td><td>⌀</td><td>✓</td></tr><tr><td>Manage info shared with 3rd parties</td><td>⌀</td><td>⌀</td><td>✓</td></tr></table> [...] What are the preset parental control restriction levels on Nintendo Switch? When setting up parental controls for Nintendo Switch, you can choose from the following preset restriction levels (or customize the restrictions yourself). Teen • Restricted Software - Games rated for ages 17+ (games rated Mature by the ESRB) • Posting to Social Media - Not Restricted • Communicating with Others - Not Restricted • Software Rating Organization - Appropriate organization for your region • VR Mode (3D Visuals) - Not Restricted	Categories	Nintendo Switch system	Smart device app	Nintendo Account	Software by age rating	✓	✓	⌀	Posting to social media	✓	✓	⌀	Communication with others	✓	✓	⌀	VR Mode (3D Visuals)	✓	✓	⌀	Play-time limits	⌀	✓	⌀	View play activity	⌀	✓	⌀	Purchase restrictions	⌀	⌀	✓	Disable Friend Suggestions	⌀	⌀	✓	Manage info shared with 3rd parties	⌀	⌀	✓
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Malikie Innovations Ltd. et al. v. Nintendo Co. Ltd. et al
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Claims	Identification
	Pre-Teen • Restricted Software - Games rated for ages 13+ (games rated Teen and Mature by the ESRB) • Posting to Social Media - Restricted • Communicating with Others - Restricted • Software Rating Organization - Appropriate organization for your region • VR Mode (3D Visuals) - Not Restricted Child • Restricted Software - Games rated for ages 8+ (games rated Everyone 10+, Teen and Mature by the ESRB) • Posting to Social Media - Restricted • Communicating with Others - Restricted • Software Rating Organization - Appropriate organization for your region • VR Mode (3D Visuals) - Restricted See, e.g., <i>Parental Controls Overview/FAQ (Nintendo Switch)</i>, Nintendo, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22508.

Claims	Identification
	Complete these steps 1. Log in to your existing parent/guardian Nintendo Account to access your Nintendo Account settings. • Only a parent/guardian Nintendo Account in a Nintendo family group can set Nintendo eShop purchase restrictions. 2. Click Family group to see a list of all supervised accounts (?) in the family group. 3. Click the Nintendo Account where you want to manage restrictions. 4. Click each setting that you want to adjust: • Spending/purchases on Nintendo Switch eShop and nintendo.com Check the box to disable purchases and auto-renewal options on Nintendo Switch AND through the My Nintendo Store (including physical orders). • Viewing of content on Nintendo Switch eShop Check Restrict to restrict the content that can be seen on the Nintendo eShop on Nintendo Switch. Content will automatically be restricted based on the player's age. 5. Click Save changes to confirm the change. See, e.g., <i>How to Set Nintendo eShop Restrictions</i>, Nintendo, https://en-america-support.nintendo.com/app/answers/detail/a_id/22444.

Claims	Identification
	The main parental controls screen on your app gives you access to many different options, including: 1. "Play-Time Limits" can be set to notify the user if they have exceeded the daily play-time limit. These settings can be set individually by day. - o "Play-Time Limit" – restricts the amount of time spent playing games. When the allotted time is up the console will not automatically turn off, but you will have the option to turn off the game remotely via the "Suspend Software" option in the Time Limits window in the app. - o "Bedtime Alarm" – allows you to notify your children of when it's time to turn off the console for the evening. 2. "Restriction Level" based on the following parameters: Teen, Pre-Teen, Child, Custom. Selecting "Custom" will allow you to make granular decisions about the content your children will have access to on the Nintendo Switch console: 3. "Restricted Software" – allows you to restrict titles based on the age of your children up to 18+. This will translate to the ESRB rating parameters. For example, if you select 13+, your console will have access to games rated EC (Early Childhood), E (Everyone), E10+ (Everyone 10+) and T (Teen). Playing of captured videos in the Album will follow the same restriction. 4. "Communicating with Others" – allows you to restrict or limit the ability to interact with other players online. This can be set on a game-by-game basis. 5. "Posting Screenshots on Social Networks" – allows you to restrict the ability to post screenshots to social networks like Twitter and Facebook. 6. "Whitelist" – allows you to add specific software titles to the whitelist to exclude them from some Parental Controls restrictions on the Nintendo Switch console. See, e.g., <i>Nintendo Switch</i>™, Entertainment Software Rating Board, https://www.esrb.org/tools-for-parents/parental-controls/nintendo-switch/.

Claims	Identification
	Customize online features Different games have different social and online features that you may want to consider. With the parental controls app, you can: • Limit sharing of in-game text or images per game • Restrict the ability to post screenshots to social media You may also set restrictions on who can make Nintendo eShop purchases via your Nintendo Account settings.* To get started, visit accounts.nintendo.com. See, e.g., <i>Nintendo Switch Parental Controls mobile app</i>, Nintendo, https://www.nintendo.com/us/switch/parental-controls/. i Play-Time Limit If you have a Play-Time Limit and a Bedtime Alarm enabled, the system will use whichever time limit comes first. ◦ <i>Play-Time Limit</i>: Set a daily limit on the amount of time the Nintendo Switch console can be used (scroll from No Limit up to 6 hours). You can also choose to remove the restriction for a specific day. ◦ <i>Bedtime Alarm</i>: Set gameplay to stop at a certain time each day (between 4:00 PM - 11:45 PM). ◦ <i>Suspend Software</i>: When this is turned on, the software on the system will be stopped when the time limit is reached. Otherwise, a notification will appear when the limit is reached, but software will still be playable. See, e.g., <i>How to Set Up, Adjust, or Remove Nintendo Switch Parental Controls</i>, Nintendo Customer Support, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22447.

Claims	Identification
	Complete these steps 1. Log in to your existing parent/guardian Nintendo Account to access your Nintendo Account settings. • Only a parent/guardian Nintendo Account in a Nintendo family group can set Nintendo eShop purchase restrictions. 2. Click Family group to see a list of all supervised accounts (?) in the family group. 3. Click the Nintendo Account where you want to manage restrictions. 4. Click each setting that you want to adjust: • Spending/purchases on Nintendo Switch eShop and nintendo.com Check the box to disable purchases and auto-renewal options on Nintendo Switch AND through the My Nintendo Store (including physical orders). • Viewing of content on Nintendo Switch eShop Check Restrict to restrict the content that can be seen on the Nintendo eShop on Nintendo Switch. Content will automatically be restricted based on the player's age. 5. Click Save changes to confirm the change. <i>See, e.g., How to Set Nintendo eShop Restrictions, Nintendo, https://en-americas-support.nintendo.com/app/answers/detail/a_id/22444.</i>

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	The main parental controls screen on your app gives you access to many different options, including: 1. "Play-Time Limits" can be set to notify the user if they have exceeded the daily play-time limit. These settings can be set individually by day. - o "Play-Time Limit" – restricts the amount of time spent playing games. When the allotted time is up the console will not automatically turn off, but you will have the option to turn off the game remotely via the "Suspend Software" option in the Time Limits window in the app. - o "Bedtime Alarm" – allows you to notify your children of when it's time to turn off the console for the evening. 2. "Restriction Level" based on the following parameters: Teen, Pre-Teen, Child, Custom. Selecting "Custom" will allow you to make granular decisions about the content your children will have access to on the Nintendo Switch console: 3. "Restricted Software" – allows you to restrict titles based on the age of your children up to 18+. This will translate to the ESRB rating parameters. For example, if you select 13+, your console will have access to games rated EC (Early Childhood), E (Everyone), E10+ (Everyone 10+) and T (Teen). Playing of captured videos in the Album will follow the same restriction. 4. "Communicating with Others" – allows you to restrict or limit the ability to interact with other players online. This can be set on a game-by-game basis. 5. "Posting Screenshots on Social Networks" – allows you to restrict the ability to post screenshots to social networks like Twitter and Facebook. 6. "Whitelist" – allows you to add specific software titles to the whitelist to exclude them from some Parental Controls restrictions on the Nintendo Switch console. See, e.g., <i>Nintendo Switch</i>™, Entertainment Software Rating Board, https://www.esrb.org/tools-for-parents/parental-controls/nintendo-switch/.

EXHIBIT H

Exhibit H - U.S. Patent No. 8,115,731

Claims	Identification
1[pre] A handheld computing device, comprising:	 To the extent the preamble is limiting, the Nintendo-branded devices include a handheld computing device.  Handheld Mode Pick it up and play with the Joy-Con™ controllers attached to enjoy the 6.2" LCD touch screen. Nintendo Store, Switch, https://www.nintendo.com/us/store/products/nintendo-switch-neon-blue-neon-red-joy-con-117972/. This is Joy-Con! One controller or two, vertical or sideways, motion controls or buttons... Joy-Con and Nintendo Switch™ give you total gameplay flexibility. Games come to life through easy-to-use motion controls and HD rumble—advanced vibration features built into each Joy-Con. Depending on the game, you might use a single Joy-Con in each hand—or even give the second one to a friend. Includes one Neon Red left Joy-Con, one Neon Blue right Joy-Con, and two Black Joy-Con Straps.  https://www.nintendo.com/us/store/products/joy-con-set-l-r-neon-red-neon-blue/

Malikie Innovations Ltd. vs. Nintendo Co. Ltd. et al.
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	 Nintendo Switch  TV mode  Tabletop mode  Handheld mode  Comes with a set of Joy-Con controllers 6.2" LCD touch screen https://www.nintendo.com/us/store/products/nintendo-switch-neon-blue-neon-red-joy-con-117972/
1[a] a display;	The Nintendo-branded devices include a display.

Malikie Innovations Ltd. vs. Nintendo Co. Ltd. et al.
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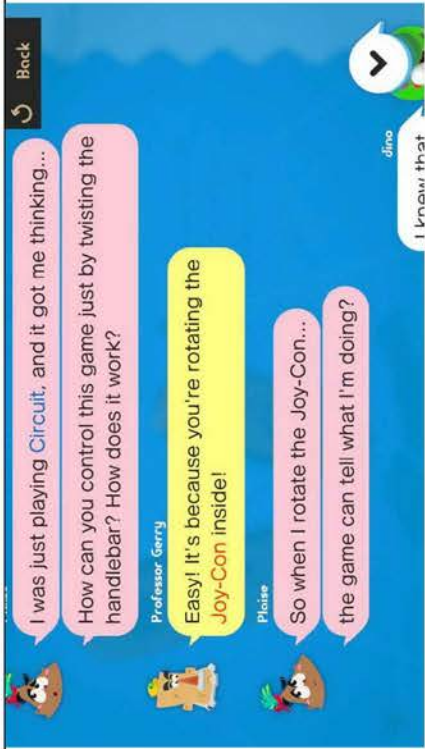
Malikie Innovations Ltd. vs. Nintendo Co. Ltd. et al.
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	 Nintendo Switch  TV mode  Tabletop mode  Handheld mode  Comes with a set of Joy-Con controllers 6.2" LCD touch screen
1[b] an internally located directional input device providing a	https://www.nintendo.com/us/store/products/nintendo-switch-neon-blue-neon-red-joy-con-117972/ The Nintendo-branded devices include an internally located directional input device providing a directional input signal, the directional input signal corresponding to an axis of inclination of the handheld computing device and indicating an orientation.

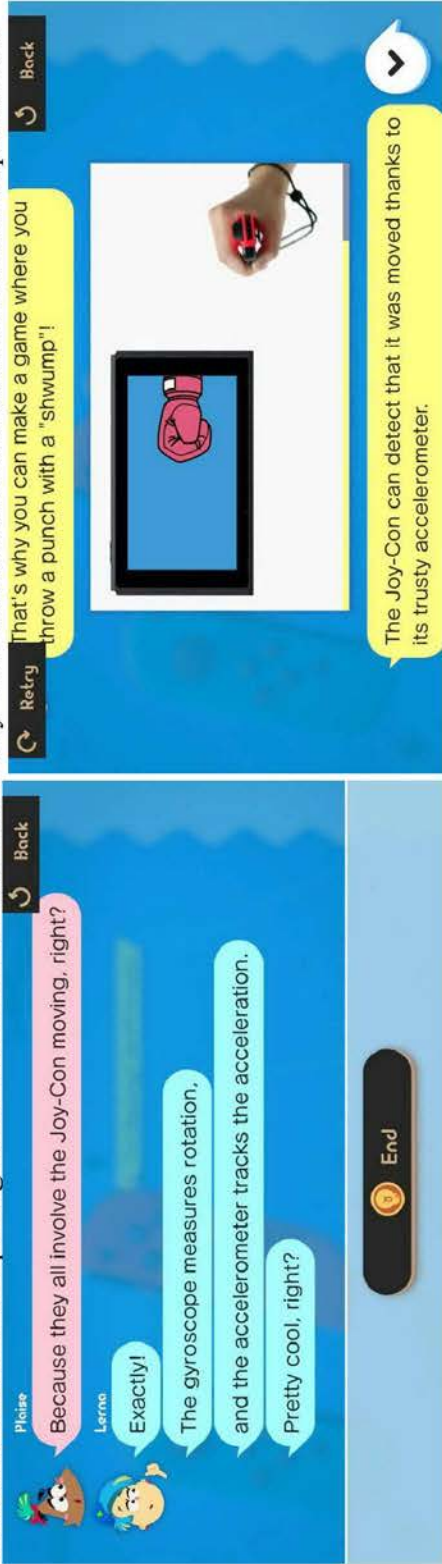
Malikie Innovations Ltd. vs. Nintendo Co. Ltd. et al.
Exhibit H – U.S. Patent No. 8,115,731

directional input signal, the directional input signal corresponding to an axis of inclination of the handheld computing device and indicating an orientation;	<table border="1"> <tr> <td data-bbox="203 915 570 1240"> Sensor </td><td data-bbox="203 577 570 915"> Joy-Con [L] Accelerometer Gyroscope Joy-Con [R] Accelerometer Gyroscope IR Motion Camera </td></tr> </table> https://www.nintendo.com/us/switch/tech-specs/#joycon-section The Nintendo Switch with Joy-Con Controller includes an internally located directional input device providing a directional input signal. Nintendo Labo, Discover Topics. The directional input signal of the Nintendo Switch with Joy-Con Controller corresponds to an axis of inclination of the handheld computing device and indicates an orientation.	Sensor	Joy-Con [L] Accelerometer Gyroscope Joy-Con [R] Accelerometer Gyroscope IR Motion Camera
Sensor	Joy-Con [L] Accelerometer Gyroscope Joy-Con [R] Accelerometer Gyroscope IR Motion Camera		

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	 Nintendo Labo, Discover Topics.
1[c] a second directional input device providing a second directional input signal, the second	 Nintendo Labo, Discover Topics. The Nintendo-branded devices include a second directional input device providing a second directional input signal, the second directional input signal indicating an amount of displacement.

directional input signal indicating an amount of displacement;	Sensor Joy-Con [L] Accelerometer Gyroscope Joy-Con [R] Accelerometer Gyroscope IR Motion Camera https://www.nintendo.com/us/switch/tech-specs/#joycon-section The Nintendo Switch with Joy-Con Controller includes a second directional input device providing a second directional input signal. Nintendo Labo, Discover Topics.
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	The second directional input signal of the Nintendo Switch with Joy-Con Controller indicates an amount of displacement.  Nintendo Labo, Discover Topics.
1[d] a processor coupled to the internally located directional input device and the second directional input device coupled to the internally located directional input device and operable to receive and process the directional input signal in conjunction with the second directional input signal; and	The Nintendo-branded devices include a processor coupled to the internally located directional input device and the second directional input device and operable to receive and process the directional input signal in conjunction with the second directional input signal. The Nintendo-branded devices include a processor coupled to the internally located directional input device and the second directional input device.