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(54) Title: HIGH-DENSITY SUBMARINE ROADM UNIT WITH REMOTE WSS REDUNDANCY

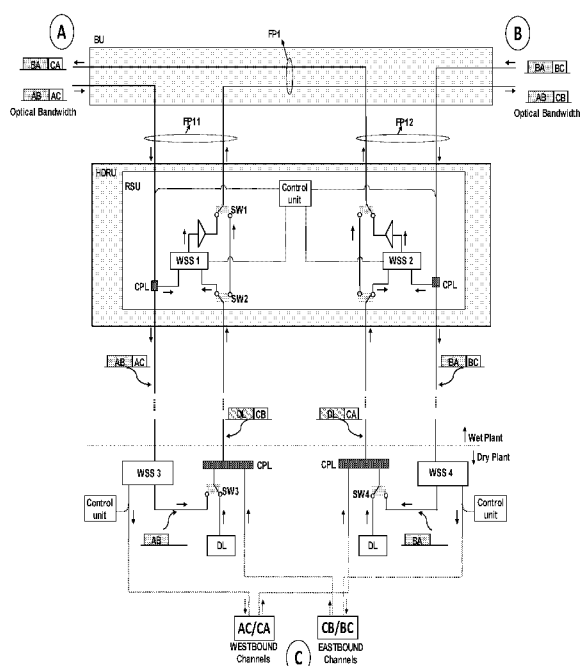


FIG. 3

(57) Abstract: Aspects of the present disclosure describe systems, methods and structures including high-density submarine/undersea re-configurable optical add/drop multiplexers (ROADM) having remote wavelength selective switch (WSS) redundancy.

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HIGH-DENSITY SUBMARINE ROADM UNIT WITH REMOTE WSS REDUNDANCY

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of United States Provisional Patent Application Serial No. 62/767,174 filed 14-NOV-2018 and United States Utility Patent Application Serial No. 16/681,813 filed 12-NOV-2019 the entire contents of both which are incorporated by reference as if set forth at length herein.

TECHNICAL FIELD

[0002] This disclosure relates generally to submarine optical communications and more particularly to submarine optical communications systems including a high-density submarine reconfigurable optical add-drop multiplexer (ROADM) and wavelength selective switch (WSS) redundancy.

BACKGROUND

[0003] As is known in the optical communications arts – and in particular the submarine/undersea optical communications art – branching units including ROADMs are fundamentally important components in such submarine/undersea systems. Known further, submarine/undersea systems having ROADMs based on WSS elements have proven to be of further importance as they provide great flexibility and reliability for the interconnection of three or more sites. Given their importance, improvements in such branching elements including ROADMs and WSS' would be a welcome addition to the art.

SUMMARY

[0004] An advance in the art is made according to aspects of the present disclosure directed to improved systems, methods, and structures including high-density submarine/undersea reconfigurable optical add/drop multiplexers (ROADM) having remote wavelength selective switch (WSS) redundancy.

[0005] In sharp contrast to the prior art, systems, methods, and structures according to aspects of the present disclosure advantageously employ remote WSS that are advantageously located in “dry plant”, while the submarine/undersea ROADM include WSS in “wet plant”.

[0006] As we shall now show and describe however, systems, methods, and structures according to the present disclosure advantageously overcome such space limitations of submarine/undersea ROADM units by employing a remote redundancy configuration for WSS elements. Advantageously, and according to an aspect of the present disclosure, redundant elements normally located inside an RU can be reduced and the number of RSUs can be doubled.

[0007] According to a further aspect of the present disclosure, submarine/undersea RSUs advantageously do not include redundant WSS elements. Instead, a system to traffic recovery methodology employing a WSS unit at a branch station is employed that may both increase the volume of add/drop operations at a particular ROADM while enhancing its serviceability.

BRIEF DESCRIPTION OF THE DRAWING

[0008] A more complete understanding of the present disclosure may be realized by reference to the accompanying drawing in which:

[0009] **FIG. 1** shows a schematic diagram of an illustrative configuration of submarine/undersea branching unit(s) (BU) and submarine/undersea ROADM units (RU) wherein each RU includes ROADM subunits (RSU) and RU1 and RU2 are separate wet-plant bodies, spaced apart by a distance of several kilometers (km) - according to aspects of the present disclosure;

[0010] **FIG. 2** shows a schematic diagram of an illustrative high-density ROADM unit (HDRU) according to aspects of the present disclosure;

[0011] **FIG. 3** is a schematic diagram of an illustrative HD-RSU configuration with remote WSS redundancy in which the configuration is in a normal-mode of operation according to aspects of the present disclosure; and

[0012] **FIG. 4** is a schematic diagram of an illustrative HD-RSU configuration with remote WSS redundancy in which the configuration is in a failure-mode operation according to aspects of the present disclosure.

[0013] The illustrative embodiments are described more fully by the Figures and detailed description. Embodiments according to this disclosure may, however, be embodied in various forms and are not limited to specific or illustrative embodiments described in the drawing and detailed description.

DESCRIPTION

[0014] The following merely illustrates the principles of the disclosure. It will thus be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the disclosure and are included within its spirit and scope.

[0015] Furthermore, all examples and conditional language recited herein are intended to be only for pedagogical purposes to aid the reader in understanding the principles of the disclosure and the concepts contributed by the inventor(s) to furthering the art and are to be construed as being without limitation to such specifically recited examples and conditions.

[0016] Moreover, all statements herein reciting principles, aspects, and embodiments of the disclosure, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure.

[0017] Thus, for example, it will be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the disclosure.

[0018] Unless otherwise explicitly specified herein, the FIGs comprising the drawing are not drawn to scale.

[0019] By way of some additional background, we begin by noting once more that branching units including ROADMs are fundamental elements in modern submarine/undersea communications systems. As will be known and appreciated by those skilled in the art, ROADMs employing wavelength selective switch (WSS) elements provide considerable flexibility and reliability when used to interconnect three or more sites.

[0020] In submarine/undersea network systems, those skilled in the art will know that it is commonplace to divide the network into “trunks” and “branches”. Typically, each branch station is connected to a pair of trunk stations by two independent fiber pairs (FPs). An amount of capacity that is added/dropped to each branch station is managed by the submarine/undersea ROADM unit (RU).

[0021] As will be known further by those skilled in the art, submarine/undersea RUs can accommodate a limited number and resulting volume of components due to the significant space/volume limitations of submarine/undersea bodies. Among the components included in an undersea/submarine RU include – among others - WSS elements, optical amplifiers, optical switches, passive optical couplers, control circuits, and command receivers and transmitters. Additionally - to increase overall reliability, certain elements included in the RU - such as the WSS - are redundant. Consequently, such RU space limitation result in a limited amount of add/drop operations that can be performed in the RU. For example, a typical submarine/undersea RU can support up to 2 add/drop operations in one housing (i.e., 2 ROADM sub-units). This means that full bi-directional

connectivity is provided for 2 trunk FPs and 4 branch FPs. In those situations where it is necessary in a particular branch to drop more fiber pairs, several RUs must be installed.

[0022] **FIG. 1** shows a schematic diagram of an illustrative configuration of submarine/undersea branching unit(s) (BU) and submarine ROADM units (RU) wherein each RI includes ROADM subunits (RSU) and RU1 and RU2 are separate wet-plant bodies, spaced apart by a distance of several kilometers (km). As illustrated in that configuration shown in the figure, 4 trunk FPs are shown with bidirectional add/drop connectivity. As may be now readily understood and appreciated - due to housing size limitation(s) - two cascaded RUs are necessarily employed. Additionally, each RSU includes redundant WSS elements to increase network reliability. Of course, such redundancy comes at a price – namely additional space in the submarine/undersea housing – which we have already noted is at a premium in such submarine/undersea systems.

[0023] As we shall now show and describe however, systems, methods, and structures according to the present disclosure advantageously overcome such space limitations of submarine/undersea ROADM units by employing a remote redundancy configuration for WSS elements. Advantageously, and according to an aspect of the present disclosure, redundant elements normally located inside an RU can be reduced and the number of RSUs can be doubled. According to a further aspect of the present disclosure, RSUs advantageously do not include redundant WSS elements. Instead, a system to traffic recovery methodology employing a WSS unit at a branch station is employed. Such high-density ROADM unit (HD-RU) employing aspects of the present is shown illustratively in **FIG. 2**.

[0024] With reference now to that **FIG. 2**, there it shows a schematic diagram of an illustrative high-density ROADM unit (HDRU) according to aspects of the present disclosure. As will be readily understood and appreciated by those skilled in the art, the reduction of RUs in submarine/undersea – as accomplished by systems, methods, and structures according to aspects of the present disclosure - is critically important as such RU

reduction further reduces cost and simplifies marine installation and recovery of such systems.

[0025] As may be observed from **FIG. 2**, the illustrative configuration shown includes a BU and submarine/undersea HDRU including a plurality (in this illustrative example, four (4)) RSUs (RSU1, RSU2, RSU3, RSU4) optically interconnected by a plurality of FPs (FP11, FP12, FP21, FP22, FP31, FP32, FP41, FP420), respectively.

[0026] **FIG. 3** is a schematic diagram of an illustrative HD-RSU configuration with remote WSS redundancy in which the configuration is in a normal-mode of operation according to aspects of the present disclosure. **FIG. 4** is a schematic diagram of an illustrative HD-RSU configuration with remote WSS redundancy in which the configuration is in a failure-mode operation according to aspects of the present disclosure.

[0027] With simultaneous reference now to those figures, we note that for clarity and simplicity in this discussion, operation is described for one direction only. Those skilled in the art will of course recognize and understand that bi-directional operation will likewise operate.

[0028] As shown in these figures, three (3) stations are illustratively shown. Consistent with our simplified discussion, traffic from station A to station B (AB), traffic from station A to station C (AC), and traffic from station C to station B (CB) is explained. As noted, explanation(s) for traffic (BA), (BC), and (CA) are identical to that explained and described herein.

[0029] With specific reference to **FIG. 3**, it is noted that during a normal operation, WSS1 unit manages add/drop channels in typical/conventional ROADM operation. The AC traffic is replaced by the CB traffic at WSS1. At the branch station - C, trunk and branch channels are separated by WSS3. One output port of WSS3 sends branch channels (AC) to a corresponding transponder of AC/CA channels. A second port of the WSS3 sends trunk channels (AB) to an optical switch SW3. Alternatively, CB traffic is generated at

station C and combined with Dummy Lights (DL) through a passive coupler. The Dummy lights are finally removed at WSS1, where AB traffic is combined to CB traffic.

[0030] Turning now to **FIG. 4**, there it shows a failure-mode operation according to aspects of the present disclosure when – for example - WSS1 fails. With reference to that figure, when WSS1 becomes non-operational, control unit at RSU issues a notification through an out-of-band channel using FP11. At branch station C, this notification is received through another control unit and optical switch SW3 is activated to change its condition. Now, instead of the dummy lights, trunk traffic is coupled to branch traffic. Simultaneously, optical switches SW1 and SW2 modify their condition after notification of WSS1 failure.

[0031] As may be observed from this figure, the illustrative configuration shown therein preserves a same end-to-end connectivity as with the normal-mode - with the exception that trunk channels now perform a round trip from the RU to the branch station. This causes an OSNR degradation of this channels that can be considered at a design stage as repair margin condition. This OSNR is recovered when the RU is replaced by a spare RU unit.

[0032] Those skilled in the art will now understand and appreciate that by employing our remote redundancy design/configuration according to aspects of the present disclosure, the number of WSS units in RSUs can be halved and the number of RSUs in the RU can be doubled, which results in significant advantages in terms of cost and submarine/undersea installation and operations.

[0033] At this point, while we have presented this disclosure using some specific examples, those skilled in the art will recognize that our teachings are not so limited. Accordingly, this disclosure should be only limited by the scope of the claims attached hereto.

Claims:

1. An improved submarine/undersea communications system configuration for communicating in a submarine/undersea transmission network comprising:
 - a submarine/undersea branching unit (BU);
 - a submarine/undersea reconfigurable optical add/drop multiplexer (ROADM) configured as a high-density ROADM (HDRU), said HDRU including a plurality of ROADM sub-units (RSUs), each individual one of said plurality of RSU having a plurality of wavelength selective switches (WSS) in optical communication with said BU;
 - the improved submarine/undersea communication system configuration CHARACTERIZED BY:
 - remote redundancy of the plurality of RSU WSS.
2. The improved system configuration of claim 1 FURTHER CHARACTERIZED BY:
 - the remote redundancy of the plurality of RSU WSS is achieved by configuring a redundant WSS for each individual one of the plurality of WSS included in in the submarine/undersea RSU, each redundant WSS being located in a non-submarine/undersea location.
3. The improved system configuration of claim 2 FURTHER CHARACTERIZED BY:
 - each configured redundant WSS is configured to provide dummy signaling to its paired WSS contained in the submarine/undersea RSU during normal operation.
4. The improved system configuration of claim 2 FURTHER CHARACTERIZED BY:
 - each configured redundant WSS is configured to disable providing dummy signaling to its paired WSS contained in the submarine/undersea RSU during a failure of the paired WSS.
5. The improved system configuration of claim 2 FURTHER CHARACTERIZED BY:

each configured redundant WSS is configured to add/drop channels instead of its paired WSS contained in the submarine/undersea RSU during a failure of the paired WSS.

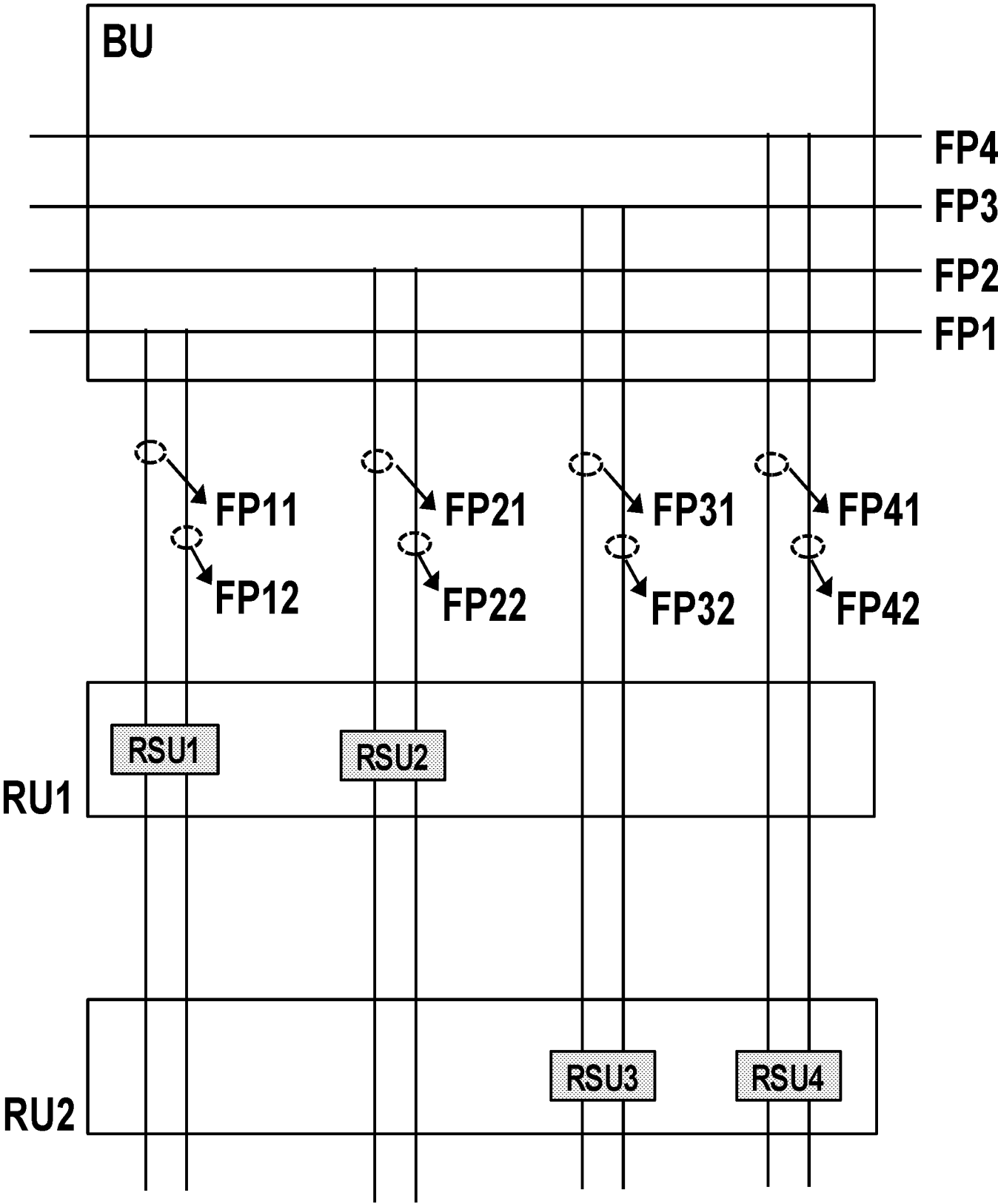


FIG. 1

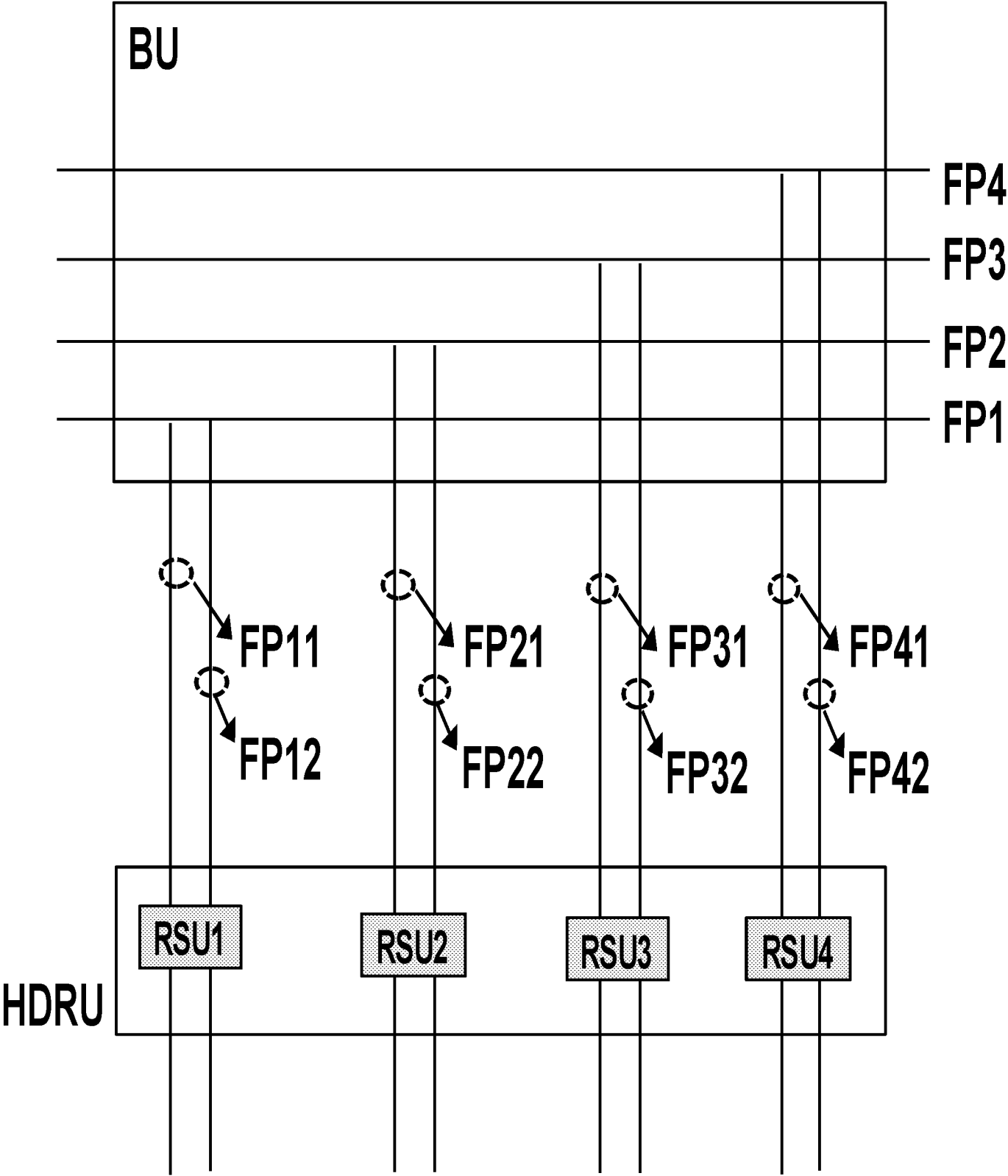
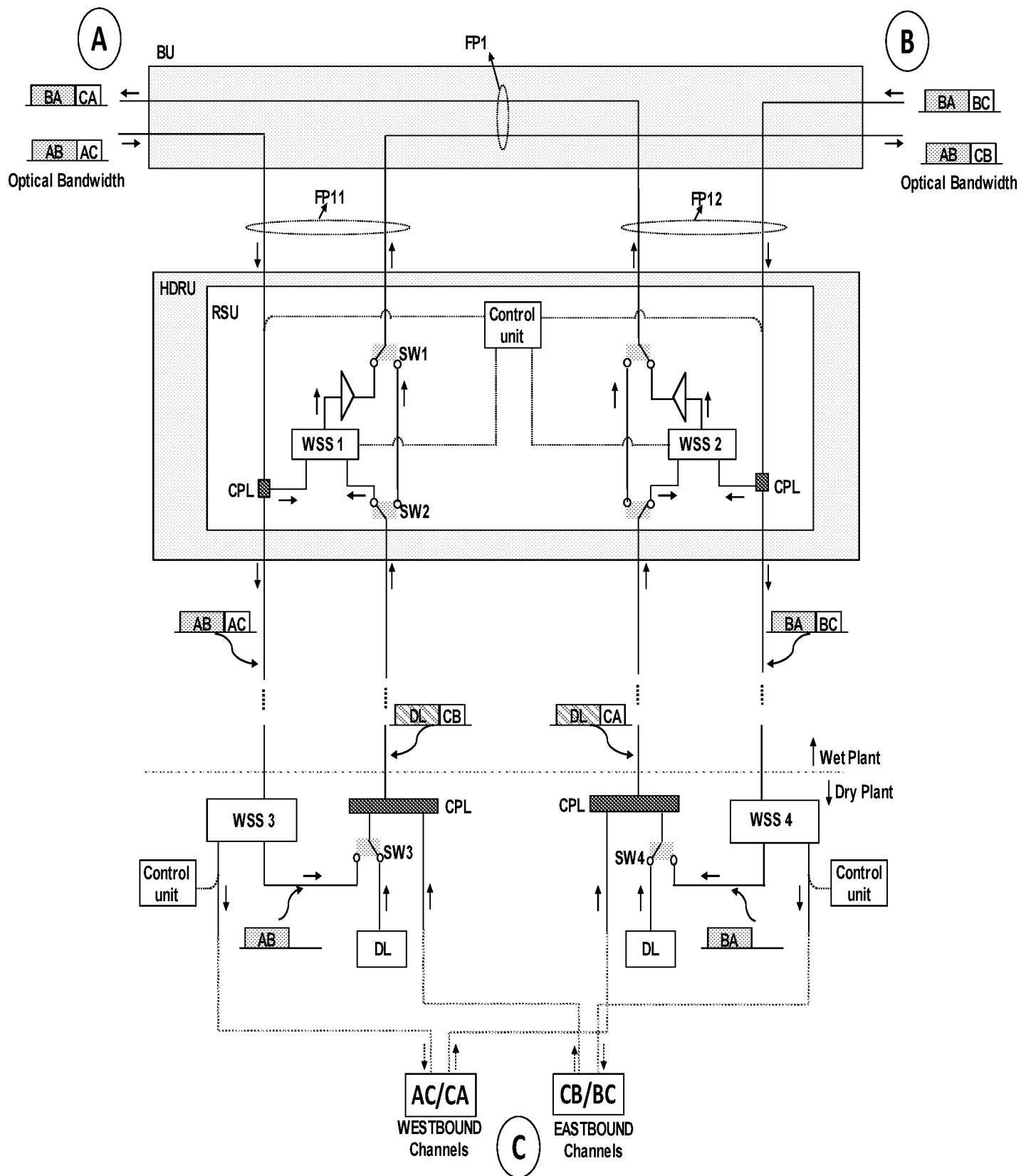
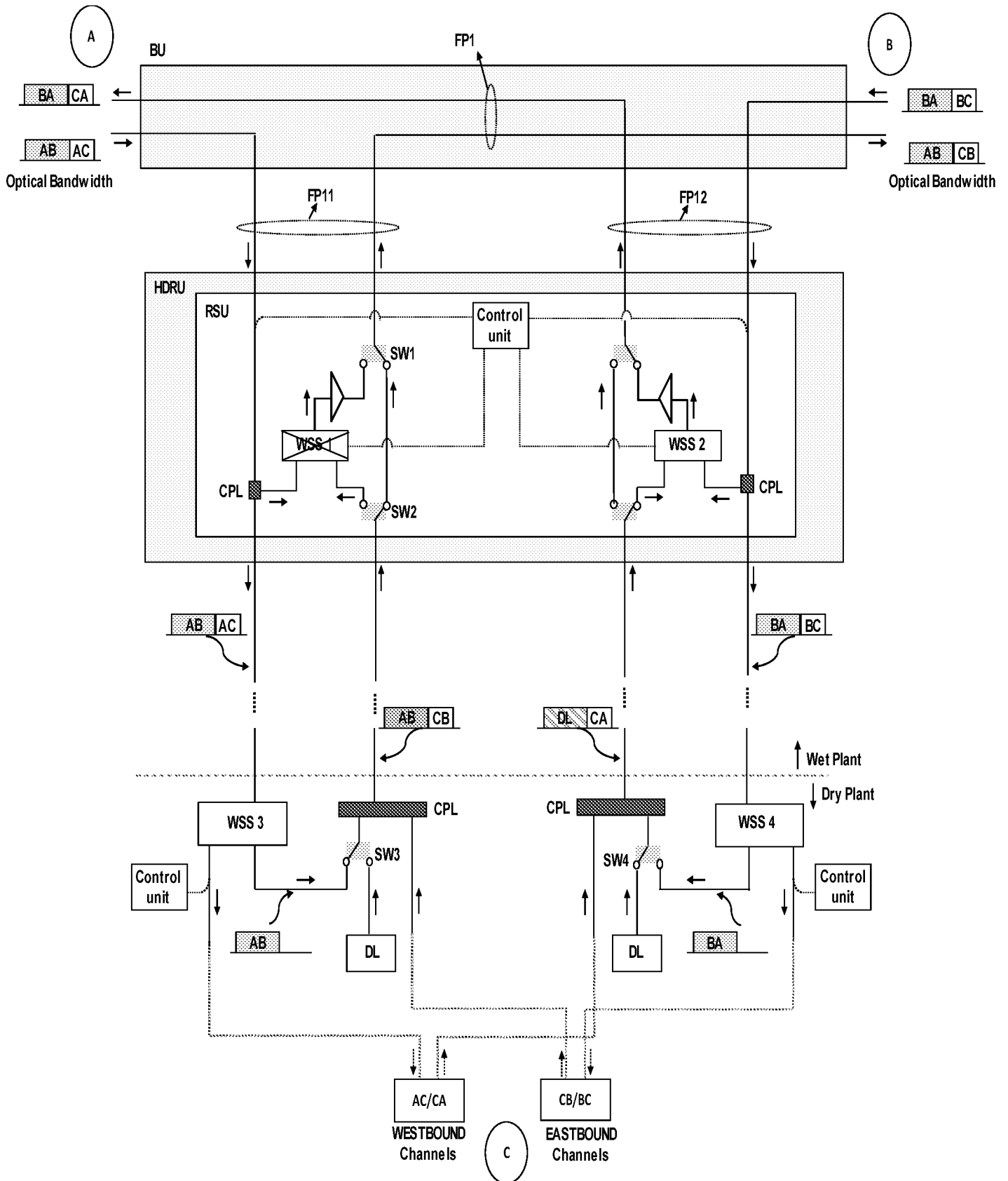


FIG. 2

**FIG. 3**

4/4

**FIG. 4**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/061063**A. CLASSIFICATION OF SUBJECT MATTER****H04J 14/02(2006.01)i, H04Q 11/00(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04J 14/02; H04Q 11/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: submarine/undersea, network, branching unit (BU), reconfigurable optical add/drop multiplexer (ROADM), units, wavelength selective switches (WSS)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2017-0117982 A1 (NEC LABORATORIES AMERICA, INC.) 27 April 2017	1-2,5
A	See paragraphs [0003], [0010], [0031], [0045]-[0057], [0072]; and figures 1-3.	3-4
Y	SORIN TIBULEAC, 'ROADM network design issues', ADVA Optical Networking, ResearchGate, 09 December 2014 [Retrieved on: 2020.02.06]. Retrieved from the Internet: <URL: https://www.researchgate.net/publication/224490738_ROADM_network_design_issues > See pages 2-53.	1-2,5
A	US 2010-0150558 A1 (PHILIP WISSEMAN) 17 June 2010 See paragraphs [0002], [0005], [0034]; and figure 6.	1-5
A	TAKEHIRO NAKANO et al., 'Innovative Submarine Transmission Systems using Full-tunable ROADM Branching Units', NEC Corporation/Submarine Networks Division, SubOptic 2016, 31 January 2017 [Retrieved on: 2020.02.06]. Retrieved from the Internet: <URL: https://suboptic.org/wp-content/uploads/fromkevin/postersession ></URL:> See pages 1-5.	1-5
A	KR 10-2015-0139696 A (VIEW TEL CO., LTD. et al.) 14 December 2015 See paragraphs [0012]-[0020]; and figure 1.	1-5



Further documents are listed in the continuation of Box C.



See patent family annex.

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

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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2019/061063

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2017-0117982 A1	27/04/2017	US 9866346 B2 WO 2017-074653 A1	09/01/2018 04/05/2017
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