Application of Core-Selective Switches to a Submarine MCF Branching Unit

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1. Introduction

Space-division multiplexing (SDM) technology is expected to be first implemented in submarine optical-cable systems. As for a new branching unit (BU) architecture for the next-generation submarine SDM era utilizing multi-core fiber (MCF), we have previously proposed a core selective switch (CSS)-based BU architecture that directly supports MCF and can branch on a core-by-core basis without fan-in (FI)/fan-out (FO) devices[1]. This BU architecture can accommodate multiple 1 × 2 fiber switch functions within a single free-space optical system, so it achieves excellent space-utilization efficiency.

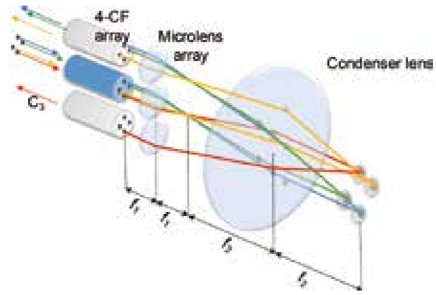
A 1 × 2 CSS optical system using a 4-core-fiber (4-CF) array is shown in Figure 1. The light beams emitted from each core of the input MCF are spatially separated by a microlens array, and they are focused by a condenser lens onto a switching mirror (one of four) corresponding to each core. Each light beam imaged on each mirror is reflected, collimated by the condenser lens and the microlens lens, and focused onto the core of one of the output MCFs with the same local core number. By adjusting the angle of each switching mirror, it is possible to output a light beam to any desired output MCF.

Since the space in a submarine BU is limited and long-term reliability is required, it is necessary to further miniaturize a submarine BU and improve its reliability so that it can practically and directly accommodate 4-CFs. Recently, we reported a submarine SDM BU comprising integrated MCF splitters and integrated CSSs. In this BU, the CSS placed on the input side in the conventional BU is replaced by a passive (and thus more reliable) all-port flipped MCF splitter[2].

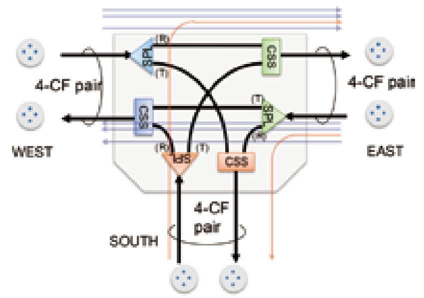
2. Configuration of broadcast- and select-type BU

A BU architecture using a "broadcast and select" (B&S) configuration based on a 1 × 2 all-port-flipped 4-CF splitter and a 1 × 2 4-CF CSS is shown in Figure 2. As a passive component, the all-port-flipped splitter is expected to reduce manufacturing costs and improve reliability. Note that when a 1 × 2 4-CF splitter is configured simply by using a half-mirror in a free-space optical system, the core position of the output light at the reflection port with respect to the direction of light travel is horizontally flipped from the incident core position. Moreover, a similar mirror inversion of core position occurs in the CSS using MEMS mirrors as switching elements; as a result, the inversion of the output CSS

■ Figure 1: 1×2 4-CF CSS optical system



■ Figure 2: BU architecture in B&S configuration



is automatically canceled at the reflection port of the splitter, and the core position does not invert between the input and output ports of the BU. However, the output light is not reflected by the mirror at the transmission port of each 1×2 4-CF splitter, so the core position from which the output light is output is not flipped horizontally, and the mirror-surface inversion caused by the output CSS is not canceled. In other words, whether core positions are flipped or non-flipped depends to the output port of the BU. To prevent incorrect connection of transmission lines throughout the entire network, it is preferable to prevent a mixture of flipped and non-flipped core positions in the BU. An all-port flipped splitter was therefore used. As for the operation of the splitter, as shown at the top of Figure 3, the light transmitted through the half mirror is sent to a total reflection mirror via relay optics, and the core position of the transmission port from which the output light was transmitted is intentionally flipped.

3. Integrated splitter and integrated CSS prototypes

As mentioned above, space is a precious and finite resource in submarine BUs, which must be as compact as possible. In general, free-space optics can process multiple beams in parallel, and that capability is advantageous for integrating multiple optical systems into a single module. Given that fact, we fabricated three integrated all-port-flipped splitters and three integrated CSSs using a free-space optical system as shown in Figure 3.

The three integrated 1 × 2 4-CF CSSs shown at the bottom of Figure 3 were adapted from three bundled 1 × 8 5-CF CSS prototypes reported in [3], of which only two of the eight output ports were used (the middle core of the five cores is not used). The left side of Figure 3 shows an enlarged image of a 5-CF bundle with three 5-CFs arranged adjacent to each other (at the vertices of an equilateral triangle) with a fiber spacing of 12.5 µm (upper image) and a MEMS mirror array (lower image). The 5-CF bundle was constructed by forming three 125-µm-diameter holes on a silicon substrate and inserting 125-µm-diameter clad 5-CFs into the holes while adjusting the rotational position of the cores. The three integrated 1 × 2 all-port-flipped 4-CF splitters (left photo) and the three integrated 1 × 2 4-CF CSSs (right photo) are shown in Figure 4.

4. Performance of BU prototype

The performance of the BU prototype, comprising the integrated splitters and integrated CSSs, was evaluated using the experimental configuration shown in Figure 5(a). A dual-polarization quadrature-phase-shift-keying (DP-QPSK) 100-Gb/s signal was combined with eight dummy wavelength channels on a 200-GHz frequency grid to form a wavelength-division-multiplexed (WDM) signal in the C-band. Four copies of the WDM signal created by a 1×2 splitter were spatially multiplexed with a 4-CF fan-in device and input into the 4-CF 1×2 all-port-flipped splitter at the south port of the BU. The output port of the 4-CF 1×2 CSS and the input port of the 4-CF 1×2 all-port-flipped splitter at the west (W) and east (E) ports of the BU were connected to emulate three cascaded BUs as visualized in Figure 5(b).

If all CSSs are set up so that all cores of the output ports select the input port to which the reflection port of the splitter is connected, an SDM signal equivalent to a signal that has passed through three BUs clockwise is output from the output port of the south (S) CSS. The accumulated XT of the clockwise path is less than dB, as shown in Figure 6(a), so no measurable optical-signal-to-noise ratio (OSNR) penalty is imposed on the bit-error-rate (BER) performance, as shown in Figure 6(b).

5. Conclusion

As an application of CSSs, a 4-CF BU prototype, comprising three integrated all-port-flipped splitters and three integrated CSSs, demonstrated that SDM signals can pass through three BUs without any OSNR penalty.

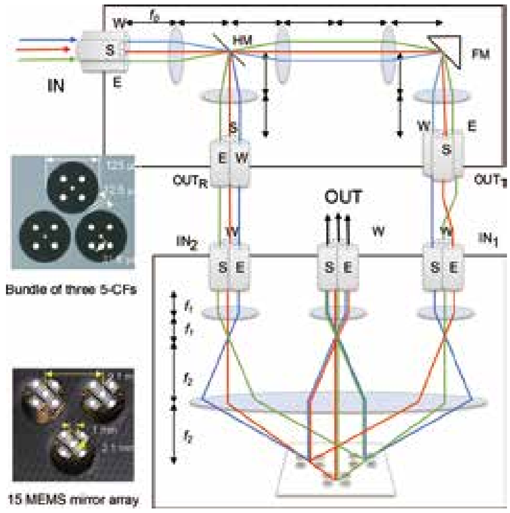
References

[1] K. Matsumoto and M. Jinno, "Core selective switch based branching unit architectures and efficient bidirectional core assignment scheme for regional SDM submarine system," Proceedings Optical Fiber Communications Conference and Exhibition (OFC), W3F.3, 2022.

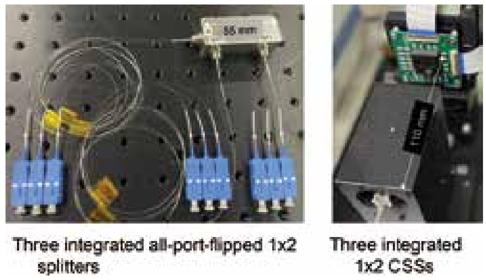
[2] R. Tahara et al., "Submarine SDM branching unit with integrated all-port flipped multicore fiber splitters and integrated core selective switches," ECOC 2023, Th.B.6.2, 2023.

[3] Y. Uchida et al., "Design and Performance of 1×8 Core Selective Switch Supporting 15 Cores Per Port Using Bundle of Three 5-Core Fibers," Journal of Lightwave Technology, vol. 41, no. 3, pp. 871-879, 1 Feb.1, 2023.

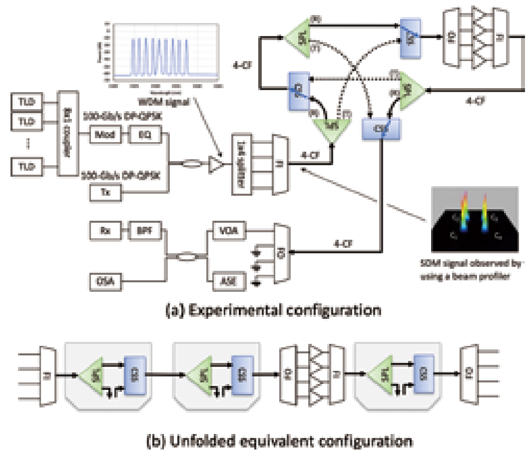
■ Figure 3: BU optical system using splitters and CSSs



■ Figure 4: All-port-flipped splitters and CSSs



■ Figure 5: Experimental configuration to verify BU prototype performance



■ Figure 6: XT and BER of clockwise path