PROGRESS TOWARDS A VIRTUAL QUADRANT RECEIVER FOR 4-ARY PULSE POSITION MODULATION/OPTICAL CODE DIVISION MULTIPLE ACCESS (4-ARY PPM/O-CDMA) NETWORKS
V. J. Hernandez\(^{1}\), A. J. Mendez\(^{2}\), R. M. Gagliardi\(^{3}\), C. V. Bennett\(^{1}\), and W. J. Lennon\(^{1}\)
\(^{1}\)Lawrence Livermore National Laboratory, Livermore, CA
\(^{2}\)Mendez R&D Associates, El Segundo, CA
\(^{3}\)University of Southern California, Los Angeles, CA

1. Introduction
Optical code division multiple access (O-CDMA) is an attractive technique that provides increased privacy in avionics communication and sensor systems [1,2]. O-CDMA encodes signals with a unique code, and these enable signals to transmit through shared fiber with minimal interference. Only a receiver with proper knowledge of the code can recover the signal. Additionally, O-CDMA potentially serves as a wavelength multiplier to traditional WDM-based technologies [3]. Although O-CDMA systems typically use on-off-keying (OOK) to apply data to the O-CDMA carrier, increased throughput can be achieved through more efficient transmission schemes, such as m-ary pulse position modulation (PPM) [4]. PPM transmits symbols as a series of pulses whose position (or slot) within a frame identifies the symbol. Unlike OOK-based detection, PPM ultimately relies on a comparison test between m slots, with a decision based on the slot containing the most energy. Implementation of this comparison test is difficult to perform without having to use high-speed electronic processing due to the narrow O-CDMA time chips (typically < 100 ps). In this paper, we report on progress towards a 4-ary PPM virtual quadrant receiver (VQR) that performs this comparison test photonicly, minimizing the number of electronic components. The device is incorporated into an O-CDMA technology demonstrator (TD) that utilizes the time/wavelength coding technique [3]. The receiver implementation lays the foundation for a compact, planar lightwave circuit (PLC)-based design, critical for reducing the device footprint within the aircraft.

2. Virtual Quadrant Receiver Concept and Simulations
The VQR maps pulses of the correctly decoded O-CDMA/PPM frame onto an xy-coordinate system, where each quadrant of the xy-coordinate system corresponds to one of the PPM slots. The following control law can perform this mapping:

\[
\text{Control Law : } (x, y) = ((\text{slot}_3 + \text{slot}_2) - (\text{slot}_1 + \text{slot}_0), (\text{slot}_3 + \text{slot}_1) - (\text{slot}_2 + \text{slot}_0))
\]

(1)

The control law can be implemented as shown in Fig. 1 using mainly optical components. Couplers perform the addition while differential receivers perform subtraction. The control law performs a comparison test by aligning all slots and sampling them simultaneously. It is therefore necessary to create multiple copies of the signal with the splitter and then realign the slots using fiber delay lines. Simulations of the VQR reveal the impact of multi-access interference (MAI) and optical beat interference (OBI), as shown in Fig 2(a-c). The superposition of 1024 PPM-received symbols (2048 bits) in the absence of MAI yields four points normalized to \((\pm 1, \pm 1)\) on the xy-coordinate plane. When other signals transmit, they produce MAI and OBI, and this causes the signals to deviate from their origins. Symbol errors occur when the decision constellation points deviate to an adjacent quadrant.

3. Virtual Quadrant Receiver Implementation and Results
The implementation of the VQR is based on the design of Fig. 1 and it is integrated into the O-CDMA TD. A PLC-based lossless splitter, which incorporates an erbium doped waveguide amplifier (EDWA), minimizes the splitting losses in the receiver. The lossless splitter can be integrated with the couplers and delay lines into a monolithic PLC chip. The D flip-flops (DFF) perform sampling, and these can be replaced with optical time gates for an all-optical implementation. The DFFs have up to 10 GHz bandwidth to properly sample the 100 ps O-CDMA pulses of the TD. The DFFs are gated at 622 MHz, corresponding to the TD symbol rate of 622 Msym/s (1.25 Gb/s). Fig. 3(a) and Fig. 3(b) respectively
show the eye diagram and time trace of the single correctly decoded PPM/O-CDMA signal into the VQR and Fig. 3(c) and Fig. 3(d) show the unsampled (pre-DFF) waveforms at the VQR x and y outputs, respectively. The resulting xy-coordinate plot is shown in Fig. 2(d), produced by plotting the sampled x and y outputs onto a sampling scope. The measurement closely matches the simulated one user result, with spurious points appearing due to imperfect alignment of the outputted DFF signals.

4. Conclusion
We described the concept, numerical simulation, and physical implementation of a virtual quadrant receiver for 4-ary PPM/O-CDMA. The simulations show the joint impact of MAI and OBI on the receiver output (constellation plot). The receiver operation was demonstrated with a physical implementation that can be ultimately integrated as a PLC-based device.

Fig. 1. PPM/O-CDMA network and 4-ary virtual quadrant receiver design

Fig. 2. Results for virtual quadrant receiver: (a-c) simulated and (d) experimental.

Fig. 3. VQR waveforms: (a) input eye, (b) input time trace, (c) x output, and (d) y output.

References

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