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Performance Analysis of Crosstalk Suppression in WDM System with Fiber Optical Parametric Amplifier

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ABSTRACT: Fiber Optical Parametric Amplifiers (FOPA) are amplifiers that are based on the third order non-linear susceptibility of glass. They are used for multi-wavelength amplification in Wavelength Division Multiplexing (WDM) systems since they can provide high gain over a large wavelength range. Non-linear properties of the fiber used in FOPA limits multi-wavelength amplification due to nonlinear crosstalks which originates from undesirable Four Wave Mixing (FWM) products and Cross Gain Modulation (XGM). But XGM is dominant over FWM in the degradation of WDM signals using intensity modulated data. Different techniques to suppress them includes the use of two orthogonal or parallel polarized pumps. Since they are also polarisation independent, polarisation interleaving of WDM signals can be used, leading to an additional improvement in the signal quality. By mitigating the crosstalks by these techniques, WDM signal quality can be improved and hence high performance FOPAs can be designed for use in WDM communication systems.

KEYWORDS: Cross Gain Modulation (XGM), Fiber Optical Parametric Amplifier (FOPA), Four Wave Mixing (FWM), nonlinear crosstalks, Polarisation Interleaving (POIN), Wavelength Division Multiplication (WDM).

I. INTRODUCTION

Optical fiber communication had tremendous growth since the 1990s because of the increasing demand for transmission capacity, due to the widespread use of Internet and the progress of multimedia technologies. One of the most important techniques to make full use of the available bandwidth of optical fiber, is to multiplex many wavelengths and transmit them through a single fiber, that is, by wavelength division multiplexing. WDM was made possible by the use of Erbium Doped Fiber Amplifier (EDFA) developed in 1990s, which amplifies signals for WDM systems. However the conventional EDFA (C-band) have a limited amplification window (1530-1562nm) and bandwidth (32 nm). Therefore alternative amplification windows outside the C-band of EDFA, including L-band EDFA (1570-1605nm), S-band (1450-1520nm), Raman amplifiers, and Semiconductor Optical Amplifiers (SOA) were investigated. But each of these has its own limitations and constraints. Thus an alternative type of amplifier, the Fiber Optical Parametric Amplifier (FOPA) is one of the most promising technologies used now [1].

FOPAs should overcome many challenges for its use in communication applications. In multi-wavelength systems, these challenges comprises of Four Wave Mixing (FWM), Cross Phase Modulation (XPM) and Cross Gain Modulation (XGM) between signals. Other major challenges for practical FOPAs include pump to signal relative intensity noise transfer and frequency/phase to signal intensity conversion. But the crosstalks due to FWM and XGM effects provide a major constraint for using FOPAs in WDM systems [2]. Several schemes can be used to suppress such crosstalks. Dual pump optical parametric amplifiers are much better than single pump optical parametric amplifiers since they provide a flattened gain spectrum with a large gain bandwidth [3, 4]. These crosstalks can be suppressed by using two Parallel Pump Optical Parametric Amplifier (2PP-OPA) or two Orthogonal Pump Optical Parametric Amplifier (2OP-OPA). Previous studies have shown that 2OP-OPA provides much better crosstalk suppression than 2PP-OPA [5]. Since FOPAs are polarisation independent, Polarisation Interleaving (POIN) of signals can also be used in 2OP-OPA which provides an additional improvement in signal quality.

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This paper includes the simulation of a four channel WDM system using 2PP-OPA with co-polarised signals and 2OP-OPA with polarisation interleaved signals. It is shown that 2OP-OPA with POIN signals provides much better performance in terms of FWM and XGM suppression than 2PP-OPA.

II. LITERATURE SURVEY

Parametric amplification is based on FWM which involves the mutual interaction of four waves through intensity-dependent refractive index. It is also referred to as the optical Kerr effect. The schematic of FOPA is shown in Fig 2.1.

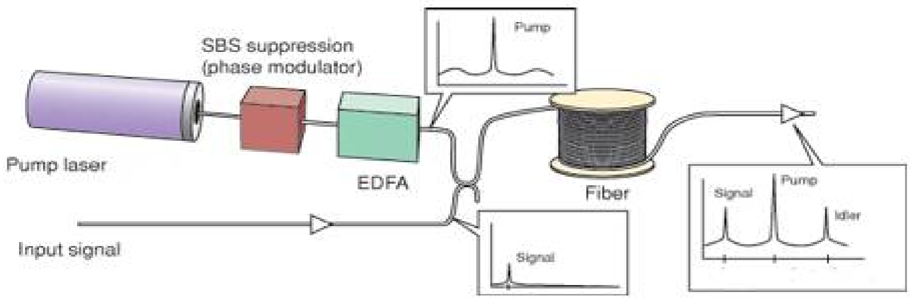

Fig. 1. Schematic diagram of fiber optical parametric amplifier

Here the pump is combined with the signal in the nonlinear medium. During the amplification process, photons will get transferred from pump wave to the signal wave and to an additional wave called the idler [6]. Due to high power of pump, Stimulated Brillouin Scattering (SBS) suppression techniques are required for the pump wave. Availability of Highly Non-Linear Fiber (HNLF) is a key component for FOPAs operating over a wide bandwidth. Amplification in FOPA is a nonlinear phenomenon exploiting the light induced modulation of the fiber refractive index. Parametric gain in optical fibers is also referred to as a third order parametric process since it rely on the third order susceptibility of the material. But the amplification is limited by the nonlinear effects in the fiber. These include FWM, XGM and Cross Phase Modulation (XPM) between signals. In particular, the signal crosstalk due to FWM and XGM effects is a major constraint on using FOPA in WDM systems. Different techniques can be used to suppress these techniques thus leading to better performance in communication systems.

III. SYSTEM DESIGN

The block diagram of a four channel WDM system with 2PP-OPA is depicted in Fig. 1. Two laser sources at 1529.45 nm and 1556.8 nm serve as the pump sources. The CW pumps are Phase Modulated (PM) by 3 Gb/s Pseudo-Random Bit Sequence (PRBS) to suppress stimulated brillouin scattering. Highly Non Linear Fiber (HNLF) with a nominal zero-dispersion wavelength of 1543.4 nm, 2 km length and a dispersion slope of 0.019 ps/nm^2 km is used as parametric gain medium. The fiber non-linear coefficient is 10.4W^{-1} km^{-1}. The Polarization Controllers (PC) after the pumps is used to align the pump's state of polarisation with PM. The two pumps are then separated by a demux and amplified by EDFAs and followed by optical filters with 0.84 nm and 1.96 nm bandwidth, respectively. These are then given to polarization controllers to ensure that the two pumps incident on the HNLF are parallel. Each pump is then amplified by a second EDFA, which provides an output power of 18 dBm and they are recombined by another WDM mux.

Here four WDM channels are used as signals and is intensity modulated. Here the PCs ensure that the signals are co-polarised. They are de-correlated by 2 km of dispersion compensating fiber. The input signal power of each channel is -6 dBm and the signal gain of each WDM channel is about 13 dB. Thus the signal output power of each channel is about 7 dBm. These signals are coupled along with the pumps into the HNLF. The output spectrum of HNLF is observed at the optical spectrum analyser and crosstalk can be measured. The isolator prevents any reflection from the Variable Optical Attenuator (VOA). After measuring the optical crosstalk, the eye diagrams, Q factor and BER are obtained using the BER analyzer.

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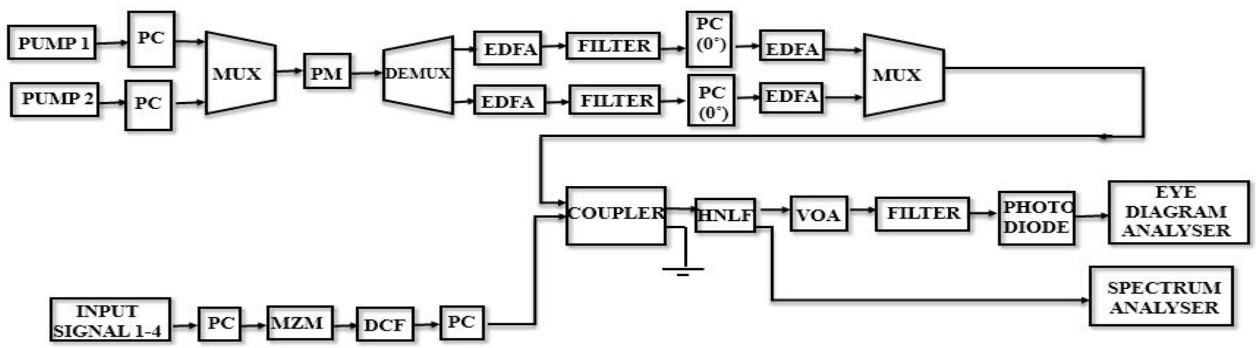

Fig. 2. Block diagram of 2PP-OPA configuration

Another technique to suppress the crosstalks is by using 2OP-OPA in a WDM system with polarisation interleaved signals. The bit streams in two neighboring channels will be orthogonally polarised. The even and odd number channels will be multiplexed together into two separate branches, whose SOPs are adjusted using polarization controllers so that they are orthogonal. A Polarization Beam Combiner (PBC) or a device known as the channel polarization interleaver create WDM signals whose neighboring channels are orthogonally polarized. The block diagram of 2OP-OPA with POIN WDM signals is depicted in Fig. 2. PC 1 and PC 2 are set at 0^o and 90^o respectively to ensure that the two pumps incident on the HNLF are orthogonal. PC3 and PC4 are used to maintain orthogonal state of polarisation between odd and even channels. Each pump is then amplified by a second EDFA which provides an output power of 21 dBm and they are combined with odd (#1,#3) and even (#2, #4) channels using couplers, respectively. The two branches are then combined with PBC. The output spectrum of HNLF is observed at the optical spectrum analyser. The eye diagrams, Q factor and BER are obtained using the BER analyzer.

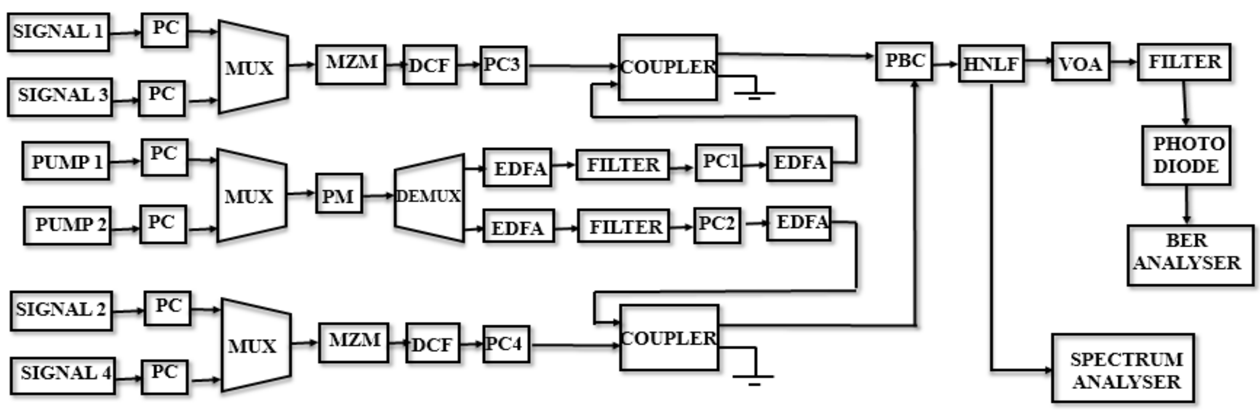

Fig. 3. Block diagram of two orthogonal pump optical parametric amplifier with POIN signals

IV. SIMULATION MODELLING

The proposed crosstalk mitigation techniques using 2PP-OPA and 2OP-OPA with POIN signals are simulated using Optisystem 12 software. The simulation setups for 2PP-OPA with co-polarised signals and 2OP-OPA with POIN signals are shown in Fig. 3 and Fig. 4 respectively.

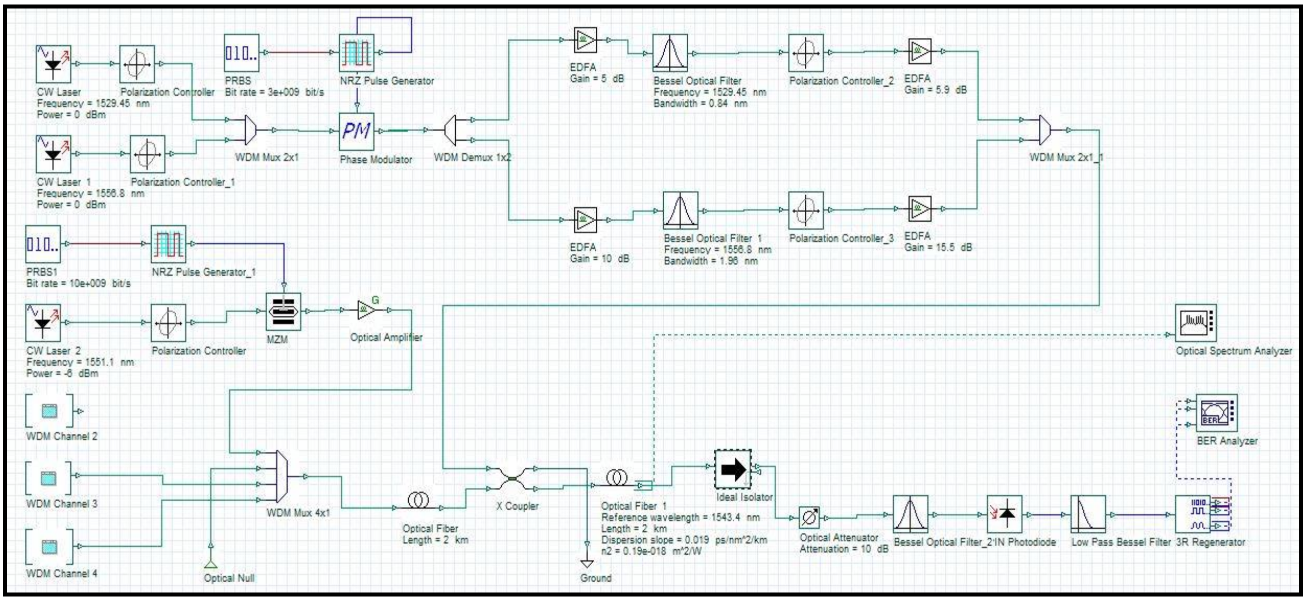

Fig. 4. Simulation setup for WDM system with 2PP-OPA

The four WDM signals are set at 1551.1nm, 1551.9nm, 1552.7nm and 1553.5nm. The subsystems shown as WDM channel 2, 3 and 4 includes PRBS, NRZ pulse generator, CW laser, PC, MZM and optical amplifier. In order to measure the FWM crosstalk more efficiently channel 2 is switched off.

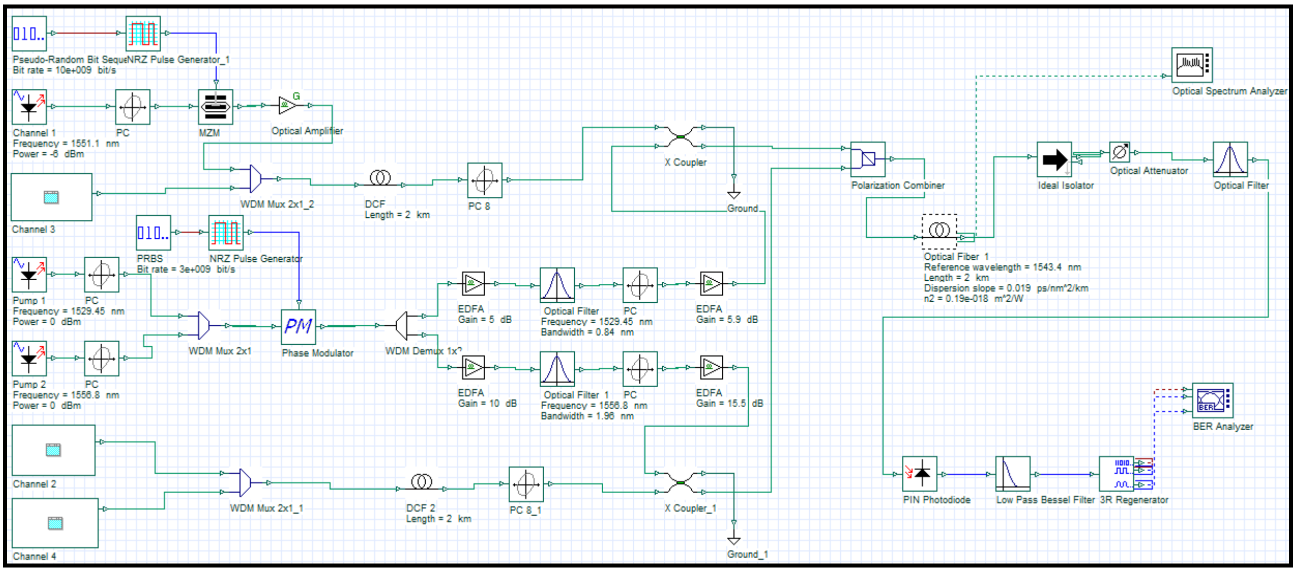

Fig. 5. Simulation setup of 2OP-OPA with POIN signals

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V. RESULTS AND DISCUSSIONS

The optical spectrums of 2PP-OPA with co-polarised signals and 2OP-OPA with polarisation interleaved signals is shown in Fig. 5(a) and Fig. 5(b) respectively. Channel 2 was switched off to measure the FWM crosstalk more easily. The crosstalk levels for 2PP-OPA with co-polarised signals and 2OP-OPA with POIN signals are -17.9 dB and -18.8 dB respectively.

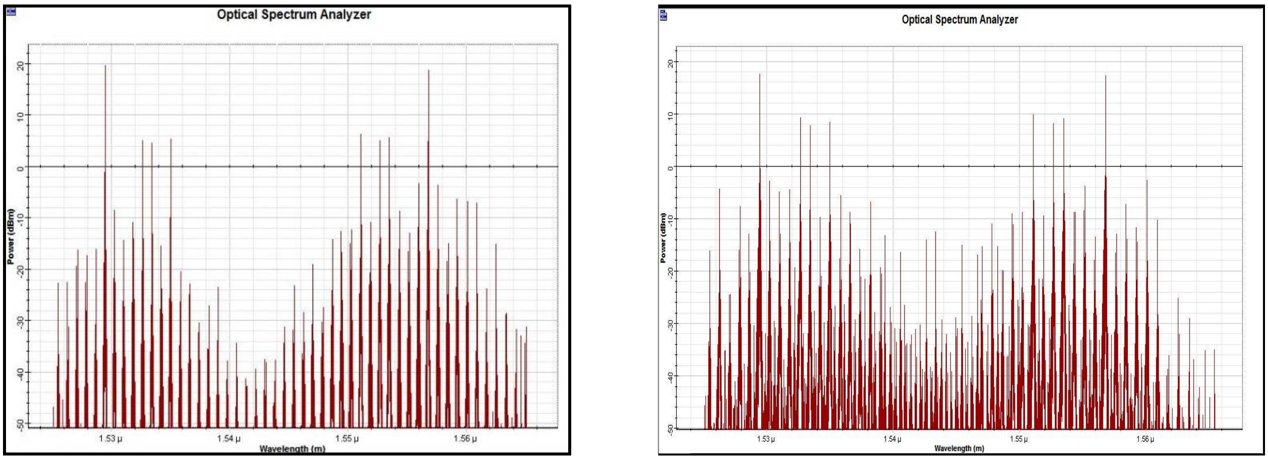
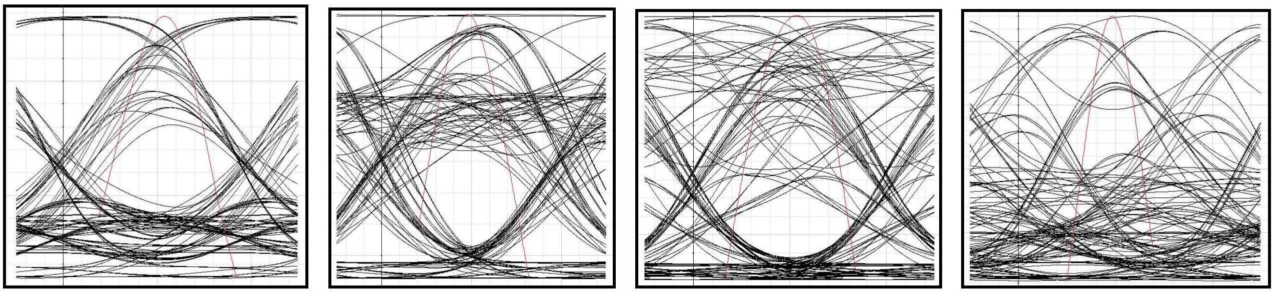


Fig. 6. Optical spectrum of (a) 2PP-OPA with co-polarised signals (b) 2OP-OPA with POIN

Both are measured with respect to channel 2 (1551.9 nm) as shown in Fig. 5. Therefore it can be seen that the FWM crosstalk level has improved in 2OP-OPA with POIN signals compared to 2PP-OPA with co-polarised signals.



(a) (b) (c) (d)

Fig. 7. Eye diagrams for 2PP-OPA at different wavelengths (nm): (a) 1551.1 (b) 1551.9 (c) 1552.7 and (d) 1553.5

The eye diagrams for 2OP-OPA with POIN signals are much better than 2PP-OPAwith co-polarised signals. This is shown in Fig. 6 and Fig. 7. This implies that the XGM crosstalk is suppressed much better in 2OP-OPA with POIN signals.

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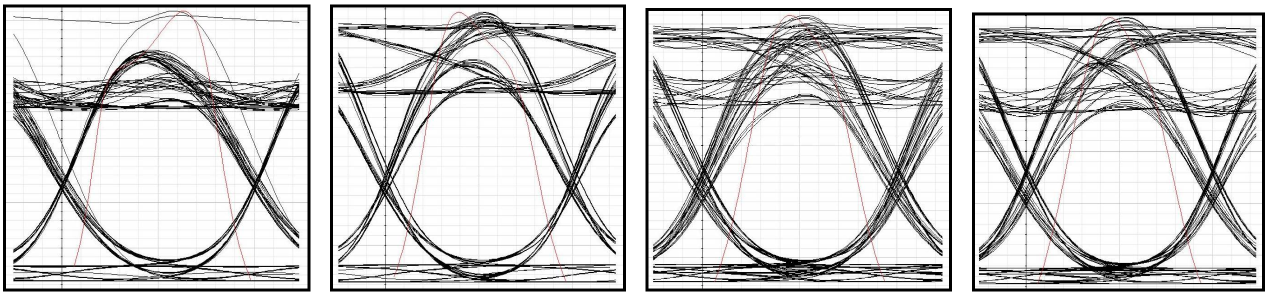

Fig. 8. Eye diagrams for 2OP-OPA with POIN signals at different wavelengths (nm): (a) 1551.1 (b) 1551.9 (c) 1552.7 and (d) 1553.5

The values of Q-factor for different WDM channels for 2PP-OPA with co-polarised signals and 2OP-OPA with POIN signals is shown in Table 1.

Table 1: Q factor for different WDM channels for 2PP-OPA and 2OP-OPA with POIN signals

Wavelength(nm)	**Q factor**	
	2PP-OPA with co-polarised Signals	**2OP-OPA with POIN Signals**
1551.1	**3.56**	**7.20**
1551.9	**3.54**	**6.72**
1552.7	**3.20**	**7.18**
1553.5	**3.02**	**6.57**

Q-factor of individual WDM channels in 2OP-OPA with POIN has been improved significantly over than that in 2PP-OPA by at least 3.08 dB. This in addition proves that 2OP-OPA with POIN is better in suppressing crosstalks.

VI. CONCLUSION

FOPAs are used as optical amplifiers in WDM transmission. The effect of various crosstalks such as FWM and XGM in FOPA can be suppressed by using 2PP-OPA and polarization interleaved WDM signals with 2OP-OPA. Better eye diagrams and Q-factor were obtained for 2OP-OPA compared to parallel pumps which shows a significant reduction in crosstalk. POIN WDM signals with 2OP-OPA configuration showed significant improvement over 2PP-OPA with co-polarised signals since FWM strongly depends on the states of polarization of neighboring channels. Hence FWM crosstalk can be easily suppressed if two channels are orthogonal to each other.

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