Nonlinear MZI as a DPSK Regenerator

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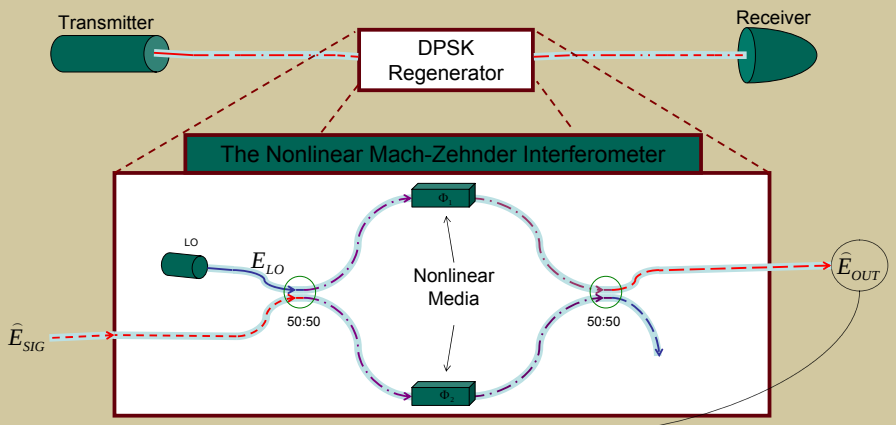
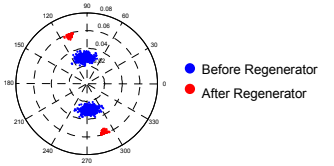
Introduction

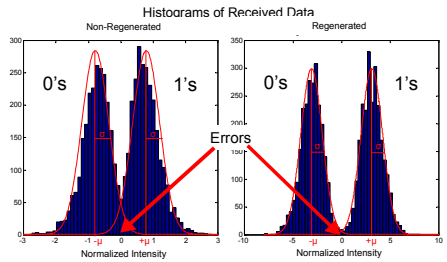
Fiber optic technology is fundamental for modern high speed long distance communication. Up until now commercial communication systems utilized simple on/off keyed (OOK) modulation formats. Recent developments indicate that phase modulation schemes provide more robust communication compared to OOK. One such scheme is differential phase-shift keying (DPSK), which encodes data as phase changes in light. In working system noise introduced by long distance propagation must be cleaned up for proper recovery at the receiver. Whereas OOK signals are only subject to amplitude noise, DPSK signals degrade due to both amplitude and phase noise. A computer model was developed for analyzing DPSK regeneration that would clean up both phase and amplitude noise based on a design using nonlinear optical interactions. Different nonlinear materials were compared for use in this design.



$$\hat{E}_{OUT} = \frac{E_{LO}}{2}\left(e^{j\Phi_2} - e^{j\Phi_1}\right) + j\frac{\hat{E}_{SIG}}{2}\left(e^{j\Phi_2} + e^{j\Phi_1}\right)$$

Regeneration Using SA

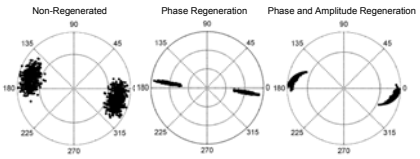




Past Work

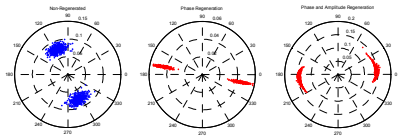
There have been several setups designed for DPSK regeneration. One design proposed by K. Croussore et al. uses a nonlinear Mach-Zehnder interferometer (MZI) with Kerr media.

Their results are shown below.



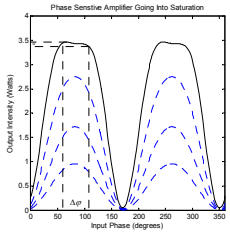
K. Croussore, C. Kim, and G. Li, Opt. Lett. **29**, 2357-2359 (2004)

Our model predictions are consistent with theirs



Concept

Nonlinear MZIs with a phase-locked local oscillator (LO) input provide phase-sensitive amplification. Small fluctuations in phase are suppressed in the output. Driving these devices into saturation causes distortion and clipping that can then be used to reduce the effect of amplitude noise.

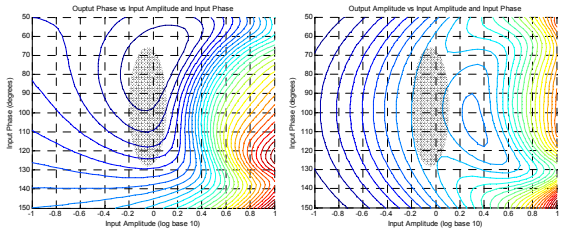


Can We Do Better With Other Media?

There are three major types of nonlinear media in addition to Kerr media. Our model shows that all four nonlinear media when used in an MZI can provide phase-sensitive amplification, however the characteristics of each provide different useful distortions in saturation that can be potentially used for regeneration.

Nonlinear Media	Φ	Effect
Kerr Media [specifically Highly Nonlinear Fiber (HNLF)]	Real	Change in phase
Saturable Amplifier [specifically the Semiconductor Optical Amplifier (SOA)]	Complex	Change in phase and gain
Saturable Absorber (SA)	Complex	Change in phase and attenuation
Two-Photon Absorber (TPA)	Imaginary	Change in attenuation

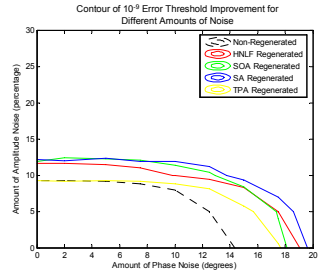
Optimizing the SA System



The contour plots of input and output phase and amplitude of MZI with SA are shown above. Best operation regions are indicated by the shaded areas where output is predominantly flat.

Results With Different Nonlinear Media

Nonlinear Media	Advantages	Disadvantages
Kerr	• Good regeneration	• Long fibers are necessary
SOA	• Great regeneration • Large amplification	• Requires external electric power supply
SA	• Great regeneration	–
TPA	–	• No amplification • Poor regeneration



Summary

Nonlinear MZIs reduce both phase and amplitude noise and can be used for DPSK regeneration. We found that best regeneration occurs with SA as the nonlinear medium in the MZI. Future research will involve using time-dependant models and designing means for LO recovery from signal.