Direct compensation of 2-D SLM phase nonuniformity within pulse shapers

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Abstract: We present a phase nonuniformity correction method for two-dimensional spatial light modulators within pulse shapers using only incoherent broadband source and an optical spectrum analyzer. Compensation results are studied with XFROG and optical-CDMA.

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1. Introduction

Arbitrary waveform synthesis, pulse shaping, and optical code division multiple access (O-CDMA) often use spatial light modulators (SLMs) as frequency domain phase and/or amplitude filters. They typically exhibit pixel-to-pixel phase nonuniformity which is unacceptable in many applications. In pulse shaping experiments, to avoid the nonuniformity problems, genetic algorithms or other feedback approaches are used to obtain the desired pulse shape [1]. Although these methods do not correct the nonuniformity, they do produce the desired output. Interferometric approaches directly diagnose the nonuniformity but require an extremely stable interferometric setup and removal of the SLM from the pulse shaper [2]. In our approach, we compensate the SLM in situ within the pulse shaper using self-referenced interferometry and a broadband incoherent source.

2. Phase Compensation Discussion

Our SLM is a reflection-mode 2D phase modulator (Hamamatsu X8267-1.5m) used in a zero-dispersion pulse shaper with fiber coupling and all-cylindrical optics. This arrangement is commonly used to encode and decode pulses in spectral phase-encoded time-spreading (SPECTS) O-CDMA network testbeds [3]. To simplify the description of our technique, we describe phase compensation for a single wavelength and a drive level corresponding to \(\pi\) radians. Broadband light from the fiber is diffracted in the horizontal dimension by the grating and it is spread vertically by beam expansion from the collimator. A single column of pixels thus samples one wavelength of the input light. By setting half of this column to \(\pi\) radians and the other half to 0 radians, the light reflected back into the fiber suffers destructive interference and is completely nulled when the phases from the two sections exactly cancel. Using this interferometry of modulated pixels vs. unmodulated pixels we measure the phase nonuniformity. Unlike traditional interferometry (e.g., Michelson interferometer), nearly all noise and path length variations are common mode to the signals, except the phase differences due to the SLM. The first step in the compensation involves searching for the half power position of the light on the vertical slice so we can interfere half of the power of the beam with a phase modulated

Fig. 1. (a) Self-interferometric phase compensation description. (b) BER statistics of SPECTS O-CDMA network testbed at 10 Gb/s/user.
version of it. We do this by sweeping a 0 to \( \sim \pi \) transition across the beam. When the transition reaches the point of evenly splitting the power of the beam, the detected power is minimized. Using this point, the beam is vertically divided into two halves. To find the drive level which corresponds to a \( \pi \) phase shift for the top half (i.e., compensated drive level), the bottom half is left at zero drive and the drive level of the top half is swept over its entire range. The drive level which minimizes the detected power is a true \( \pi \) phase shift for the top half. This process is repeated, but with the top half held at zero drive while the bottom half drive level is swept to find the value that corresponds to a \( \pi \) phase shift. These compensated drive levels are then averaged to produce an average compensated \( \pi \) drive level for the column. Using the pulse shaper, an incoherent broadband source, and an optical spectrum analyzer (OSA), this process can be performed simultaneously for all wavelengths (horizontal positions on the SLM). The resulting compensation yields the correct drive level for a \( \pi \) shift at each wavelength at the resolution limit of the pulse shaper or OSA.

Cross-correlation frequency-resolved optical gating (XFROG) [4] was used to characterize the spectral phase applied by the SLM in the pulse shaper. A 0.5-ps pulse is passed through the pulse shaper and used with a transform limited, 2.5-ps gate pulse to generate the XFROG trace (100 ps by \( \sim 15 \) nm). The narrow spectral width of the gate pulse, along with its width, yields relatively simple and intuitive XFROG traces. To capture all of the encoded pulse’s features, we only need to bin to a 256 \( \times \) 256 grid and the retrieval errors were between 0.002 and 0.005 for the both the simple and more complex XFROG traces.

![Fig. 2. Effects of uncompensated (blue) versus compensated (red) SLM phase for O-CDMA pulses retrieved using XFROG. (a) Compensation shortens pulse from 700 fs to 500 fs. (b) Spectral power and phase of signal pulse with \( \pi \) phase shift applied. (c) Encoded O-CDMA pulse spread in the time domain and its (d) spectral intensity and phase. (e) Correctly decoded O-CDMA pulse in the time domain and its (f) spectral intensity and phase.](image-url)

3. Conclusion

Crucial to SPECTS O-CDMA are uniform and accurate \( \pi \) levels as applied in the spectral domain. Fig. 2 shows phase compensated vs. uncompensated O-CDMA pulses. The compensated \( \pi \) level is uniform and accurate as shown by three different scenarios: uniform \( \pi \) level applied, encoded O-CDMA pulse, and correctly decoded O-CDMA pulse. Figs. 2(a) and (b) show the temporal and spectral characteristics after passing successively through two different channels of the pulse shaper, each applying a constant \( \pi \) phase to the spectrum of the pulse. Figs. 2(c) and (d) show a phase encoded O-CDMA pulse. With compensation, the phase jumps are uniform and very close to \( \pi \). In the time domain, incorrect encoding leaves energy at the original pulse cent (0 ps). Figs. 2(e) and (f) show a correctly decoded pulse (i.e., the same phase code is applied again). Ideally, the decoding should produce 0 to 2\( \pi \) phase jumps, which would appear as a flat phase level in the retrieved spectrum due to phase wrapping at 2\( \pi \). Compensation shows a major improvement in the uniformity of the 0 to 2\( \pi \) phase jumps.

The quality of the compensation was also proved using the SPECTS O-CDMA testbed by measuring the
bit error rate (BER) with and without SLM compensation for both two and eight users present. Accurate $\pi$ phase transitions improve the O-CDMA receivers ability to reject incorrect users, and simultaneously improves detection of the intended user. Fig. 1(b) shows $\sim$1 dB improvement in BER performance for both the 2-user and 8-user cases.

References

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