360 Gb/s Data Modulation With Dispersion Precompensation Using Optical Arbitrary Waveform Generation

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Abstract: We demonstrate a modulation format transparent optical-arbitrary-waveform transmitter at 360 Gb/s including precompensation for dispersion. Proof-of-principle transmission of 9-bit OOK and DPSK signals across a 10-km SMF link are demonstrated with spectral efficiency of 0.53-b/s/Hz.

Spectrally efficient, high-speed data transmission over conventional single mode fiber is desired for seamless upgrades to future networks. High-capacity transmissions typically require very high-speed electronics with dispersion compensation, or parallel modulations of multiple individual lasers on an integrated [1] or discrete platforms.

Optical arbitrary waveform generation (OAWG) can provide waveforms of any shape in amplitude and phase. An example of an arbitrary waveform could be a simple chirped pulse used for LIDAR, or a very complex waveform like a Tb/s psuedo-random bit-sequence (PRBS) in an advanced modulation format. The transmitter is also cost-effective through parallel methodologies of the THz waveform generation process into GHz frequency electronics. Unknown amount of linear and high-order fiber dispersion can be pre-compensated for dispersion-penalty-free transmission over any fiber lengths. Recently, waveform shapers (WS) using bulk-optics or arrayed waveguide gratings (AWGs) have successfully created truly arbitrary waveforms using line-by-line Fourier synthesis[2, 3], which involved independent amplitude and phase modulations of individual spectral lines of an optical frequency comb (OFC). Previously, line-by-line OAWG with DC modulation was used to generate 8-bit return to zero (RZ) pulse packets[4] and variable 20 to 160 GHz pulse trains [5]. This paper demonstrates OAWG as a modulation-format transparent, spectrally efficient, 360 Gb/s transmitter capable of modulating PRBSs with inclusion of fiber dispersion precompensation of the signal. In contrast to wavelength division multiplexing (WDM) and orthogonal frequency division multiplexing (OFDM), the OAWG transmitter with high-speed modulators will coherently combine N 40 GHz modulated optical comb lines from an OFC producing a continous, gapless spectrum N×40 GHz wide. Any waveform can be created with this bandwidth constraint including WDM or OFDM signals and potentially ultra-high data rate (>1 Tb/s) communication signals of an advanced modulation format.

The proof-of-principle OAWG transmitter demonstration uses a 40 GHz silica-AWG pair WS to generate high-fidelity 9-bit 360 Gb/s OOK and DPSK packets prepared for back-to-back measurement and precompensated for measurement before and after 10 km of single mode fiber (SMF) fiber transmission. Unlike prior demonstrations, full characterization of the amplitude and phase allows for generation of true high fidelity communication packets.

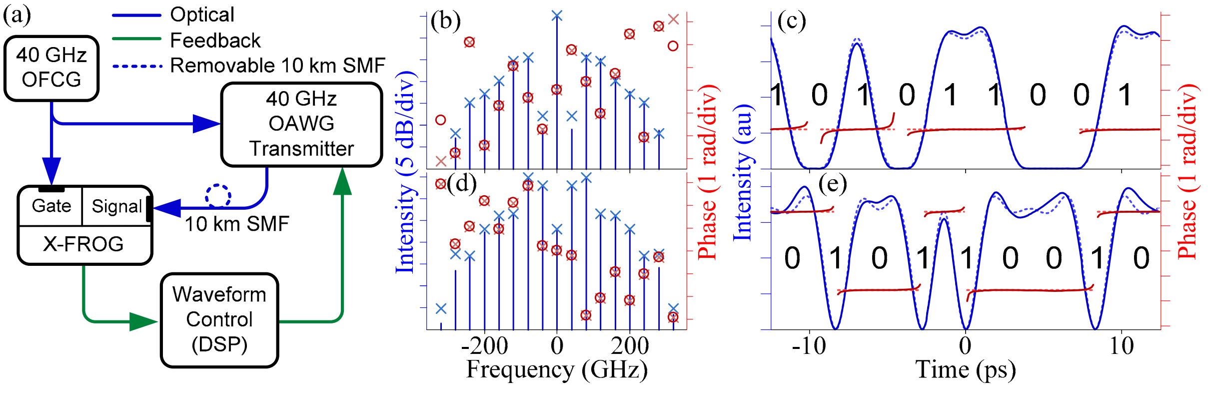

Fig. 1. (a) Experimental setup. Measured spectral intensity (stems) and phase (circles) for a (b) 101011001 OOK signal and (d) 001011001 DPSK signal. Target values ('×'). Measured temporal intensity (blue) and phase (red) for the (c) OOK signal and (e) DPSK signal. Target values (dashed).

Fig. 1(a) shows the experimental setup for generation, measurement, and transmission of the PRBS packets. Fig. 1(b,d) show the spectra to be replicated via Fourier synthesis to generate the time-domain packets [Fig. 1(c,e)]. The OFCG produces 17 spectral lines spaced at 40 GHz. The amplitude and phase of each line is controlled by the same 40 GHz silica AWG-pair WS with 128 wavelength channels used in Ref. [3]. Each wavelength channel has a resistive heater based amplitude and phase modulator with 30 dB extinction and over 2π phase shift respectively. The

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intensity and phase of the generated waveforms are precisely characterized using mode-resolved cross-correlation frequency-resolved optical gating (X-FROG). Prior demonstrations of X-FROG achieved ~0.01 radian per mode accuracy[3, 6].

The target OOK and DPSK packets are generated in the time-domain and Fourier-transformed to determine the target spectra. We generate the waveforms by first creating an impulse train at 360 Gb/s with one impulse every 2.8 ps. Then OOK or DPSK modulation is applied, and the modulated impulse train is passed through a raised cosine filter with roll-off factor of 0. This raised cosine filter ensures that the target waveform is bandlimited to match our OFCG bandwidth constraint. Additionally, a unique property of the raised cosine function is a point of zero ISI at each impulse location. The data packets used in this experiment are 101011001 for OOK and 001011001 for DPSK. Arbitrary sequences of data packets could also be generated. Fig. 1(c,e) show the measured and the target packets across the entire measurement window (25 ps). The shaping errors, the difference between the target and measured spectrum, of each packet is less than 0.01 rad per mode across the central 15 modes. Correspondingly, the measured packets in the time-domain closely match the targets in both intensity and phase. The intensity ripples are characteristic of the applied raised cosine filter. For the DPSK packet, it is clear that there is a π phase change for each 1-bit. The transmitter can also be set to precompensation for any order of fiber dispersion by adding the inverse of the spectral phase accumulated in fiber to the target spectral phase. The dispersion of the 10 km SMF was measured using the RF phase shift technique. The dispesion and dispersion slope at 1550 nm are 168 ps/nm and 0.6 ps/nm^2, respectively. Using these dispersion values the inverse dispersion was added to the target spectral phase. The precompesnated packets are shaped and measured at the transmitter, then transmitted through 10 km SMF and measured again. Fig. 2a shows the target and measured OOK packet at the transmitter precompensated for 10 km of SMF transmission. The packet is predispersed and the data is unrecognizable, but after propagating through the fiber the desired OOK packet is recovered (Fig. 2b) and matches the target packet shown in Fig. 1c. Likewise, the transmitted DPSK packet, Fig. 2c, is pre dispersed and the data unrecognizable. After 10 km transmission the measurement closely matches the target waveform (Fig. 2d)

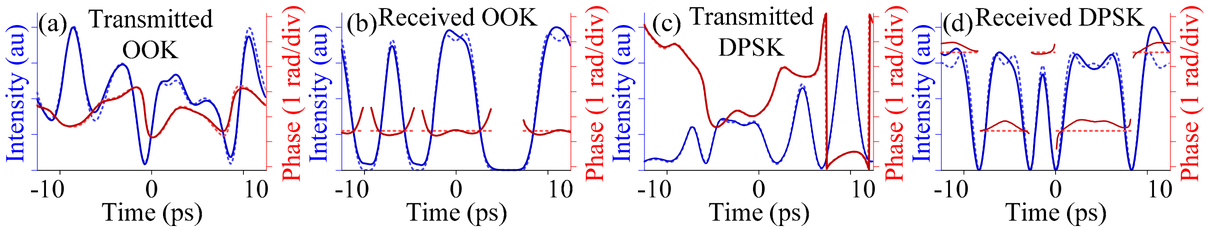

Fig. 2. Precompesnated (a) OOK and (c) DPSK packets at the transmitter. Received (b) OOK and (d) DPSK packets after 10 km propogation. Measurements (solid) and targets (dashed).

The shaped waveform will have features proportional to the inverse of the OFC bandwidth and the same repetition rate of the OFC, thus limiting the length of the waveform. Applying high-speed modulation at the repetition rate of the OFC can extend the length of the waveform allows for generation of THz waveforms using only GHz modulations. Future experiments across further transmission will increase the record length and bit rate using higher resolution AWG WSs and broader OFCs. This preliminary demonstration of the OAWG transmitter shows a modulation format transparent, variable bit rate transmitter capable of precompensating fiber transmission impairments greatly simplifying receiver design.

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