Phase Characterization of an InP based Optical-CDMA Encoder Using Frequency-Resolved Optical Gating (FROG)

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Abstract: We demonstrate the optical phase characterization of a monolithically integrated InP optical-CDMA encoder/decoder chip using frequency-resolved optical gating.

Introduction: Spectral Phase EnCoded Time Spreading (SPECTS) based Optical Code Division Multiplexing Access (O-CDMA) systems have the potential of providing very flexible access of high-network capacity to multiple end users [1]. Large-scale deployment of these systems requires a compact chip level technology, as offered by photonic integration on InP [2]. A key element of the photonic chip system is the spectral phase encoder. The encoder slices the spectrum of an ultra-short pulse into N spectral channels using an AWG, applies an individual phase shift to each channel (the phase code), and multiplexes the spectral slices to reconstruct the encoded pulse in the time domain. Proper operation of the encoder requires detailed knowledge of the phase response of each individual spectral channel for two reasons: calibration of the phase shifter response with current or voltage bias; and compensation of the initial phase errors that are present due to fabrication tolerances.  

Measuring the phase response of the encoder is a challenging task. Phase information can be extracted from an encoder by detecting the coherent beating between two encoder spectral channels [3]. This approach requires the precise alignment of two axial modes from a mode-locked laser signal with two encoder channels, which is not straightforward to implement. Furthermore, coherent beating response from encoders with >40GHz channel spacing requires sophisticated electronics for detection.

This paper demonstrates the phase characterization of an InP based encoder chip, using the Cross Frequency-Resolved Optical Gating (X-FROG) technique [4]. The X-FROG is straightforward to implement, applicable to encoders with large (>40GHz) channel spacings and it avoids the precision spectral alignment requirements in the coherent beating approach.

Operation Principle and Design: Fig. 1(a) shows the layout of the InP based SPECT O-CDMA encoder. The encoder encodes a sub-picosecond pulse in three consecutive steps. First, it spatially separates spectral slices from a 500 fs mode-locked laser pulse into eight channels (AWG-1). Second, it phase shifts each channel independently by either 0 or $\pi$ radians (the spectral code) through the phase modulator array. The delay lines behind the phase modulators equalize the optical path lengths of all channels. Finally, the phase-shifted slices are recombined to form the time domain encoded pulse (AWG-2). Applying a phase code spreads out the short input pulse in the time domain by tens of picoseconds. The O-CDMA decoder is identical to the encoder and performs the conjugate operation. With the proper conjugate code, the decoder recovers the original short pulse that can then be detected by a thresholder. Improperly decoded pulses remain spread out in the time domain and undetected.

The AWGs in the encoder have eight channels at 180 GHz channel spacing, a Free Spectral Range (FSR) covering 12 channels, and a central wavelength of 1548nm. The phase modulators are reverse biased p-i-n junctions with negligible power consumption (<1mW). The overall chip size is 10 mm x 4 mm. Fabrication details were discussed previously in [2].

Measurements: Figure 1b shows the experimental set-up. The mode-locked laser and compressor generated 0.5 ps pulses with a repetition rate of 10 GHz. A polarization controller (PC) put the pulses in TE polarization before a lensed fiber injected them into the encoder chip at 10dBm. At the chip output, a dispersion compensated EDFA amplified the encoded pulse and fed it into the X-FROG through a PC. The amplified uncompressed pulse of the mode-locked laser served as reference for the X-FROG.

The FROG traces were pre-processed by subtracting the mean of the background, low pass filtering, and corner suppressing [5]. Subsequently, the traces were spline-interpolated on a 256 x 256 grid. The error in the FROG extracted phase is typically ~5deg.

Fig 1(a) O-CDMA encoder/decoder photonic chip layout. (b) Measurement set-up for X-FROG.
Figure 2a shows the X-FROG trace of code $x0\underbrace{xxxx}_0x$, where the 0’s and x’s correspond to the voltages applied to the eight phase shifters. Figure 2b shows the pulse spreading in the time domain of the encoder output, extracted from the FROG trace. Figure 3a displays the phase of the encoder output in the wavelength domain, extracted from the FROG traces at $x=0V$ (unencoded) and at $x=14V$ reverse bias. The big dots denote the positions of the center wavelengths of the channels and their phase. Phase spikes in between the channels have been shaded out, because there is only insignificant power at those wavelengths. The different channels do not have the same phase in the unencoded trace. This is due to initial phase errors in the chip and the phase profile of the encoder input pulse. Comparing the 14V trace and the 0V trace shows that the phase change as a result of the applied code matched the code perfectly. Figure 3b shows the phase change after applying the code at 7V and 14V reverse bias, respectively, with the phases in the unencoded pulse (0V) normalized to 0 Rad. The phase shift amounts to $\pi/(40V)$. These results show both the proper operation of the InP encoder and the usefulness of FROG as encoder characterization tool.

**Conclusion:** We demonstrated the phase characterization of a monolithically integrated InP based O-CDMA encoder using X-FROG. The phase response of the encoder chip was in good agreement with the applied phase code. Overall, FROG demonstrated to be a valuable tool for measuring phase error and phase shifter performance in the encoder chip.

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**References:**


