Simplified Coherent Transceivers for Optical Communication Networks

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Theocratical Overview

- Coherent optical schemes require two optical hybrids and four pairs of balanced photodetector. It formulate a solution for medium-to-long-reach applications, however, cost of such receiver become an obstacle in short reach application like PON, inter-data-center communications and metropolitan network.

- Kramers-Kronig transceiver provides a solution for such short links. It allows the reconstruction of complex constellation from an intensity measurement using a single-photo-diode.

- The kramers-Kronig scheme relies on identifying a condition which ensures that the received signal is minimum phase.

- The following few slides would give a comprehensive overview about the working principle Kramers-Kronig receiver.

1. What is minimum phase signal?

- A necessary and sufficient condition for a complex signal $A(t) = A_s(t) + \bar{A}$ to be minimum phase is that the curve described in a complex plane by $A(t)$ when $t \to -\infty$ to $t \to \infty$ **does not encircle the origin**.
  where, $A_t \to$ Single sideband (SSB) signal & $\bar{A} \to$ DC value.

- A minimum-phase signal has an useful property that the **natural logarithm** of the magnitude related to the phase angle by the Hilbert transform.
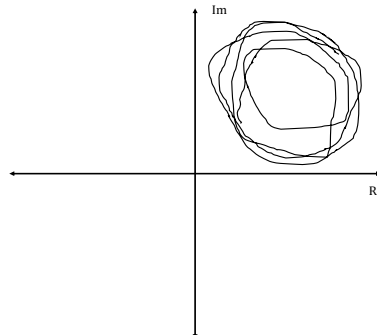
Minumum Phase Signal

2. How we can use these signals and profit from them?

- **SSB Signal:**

  If we denote a SSB signal $A_s(t)$ as,

  $$A_s(t) = A_{s,r}(t) + iA_{s,i}(t) \tag{1}$$

  then in the equation 1, the real and imaginary parts $A_{s,r}(t)$ and $A_{s,i}(t)$ are related through the Kramers-Kronig relation with each other as,

  $$
  \begin{aligned}
  A_{s,r}(t) &= -\frac{1}{\pi} p.v. \int_{-\infty}^{\infty} \frac{A_{s,i}(t')}{t - t'} dt' \\
  A_{s,i}(t) &= \frac{1}{\pi} p.v. \int_{-\infty}^{\infty} \frac{A_{s,r}(t')}{t - t'} dt'
  \end{aligned}
  \tag{2}
  $$

> **Note** : Single sideband signal is the frequency translated version of an analytical signal as,
>
> $A_s(t) = Re\{[s(t) + i\hat{s}(t)]e^{i2\pi f_0 t}\}$

- **Minimum Phase Signal:**
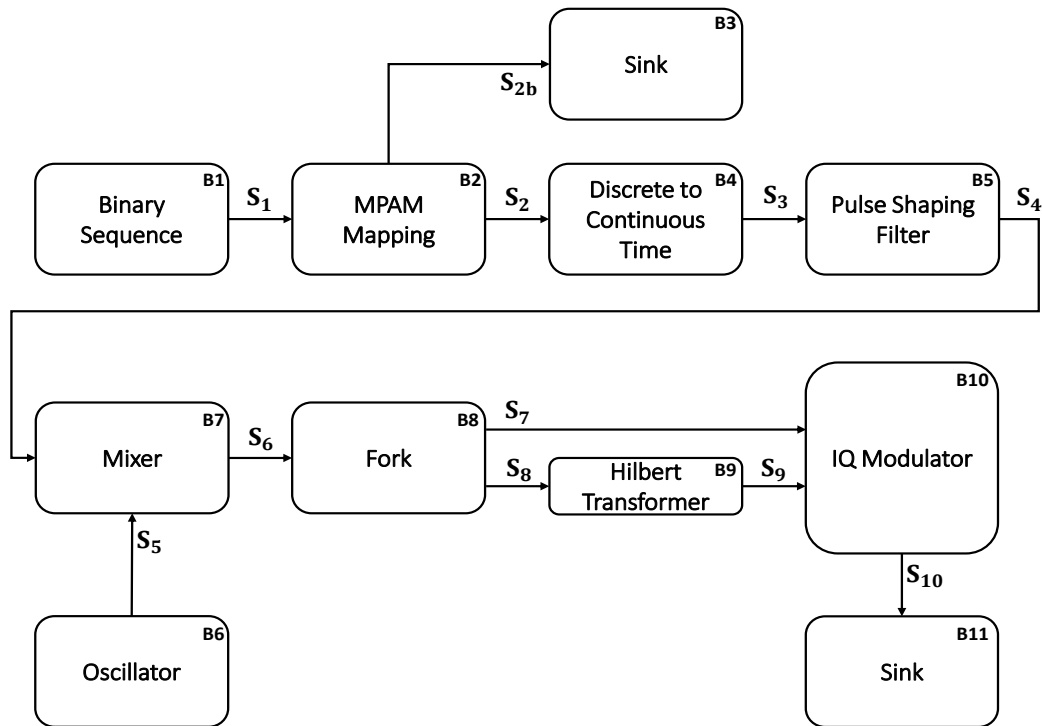 Given function $A(t) = A_s(t) + \bar{A}$ never encircles the origin for $t \in (-\infty, \infty)$.

  $$G(t) = ln\left[\frac{A(t)}{\bar{A}}\right] \tag{3}$$

  Under the hypothesis of signal being minimum phase, the phase information can be reconstructed by from its intensity as,

  $$\phi(t) = \bar{\phi} + \frac{1}{2\pi}p.v. \int_{-\infty}^{\infty} \frac{ln|A(t)|^2}{t - t'}dt' \tag{4}$$
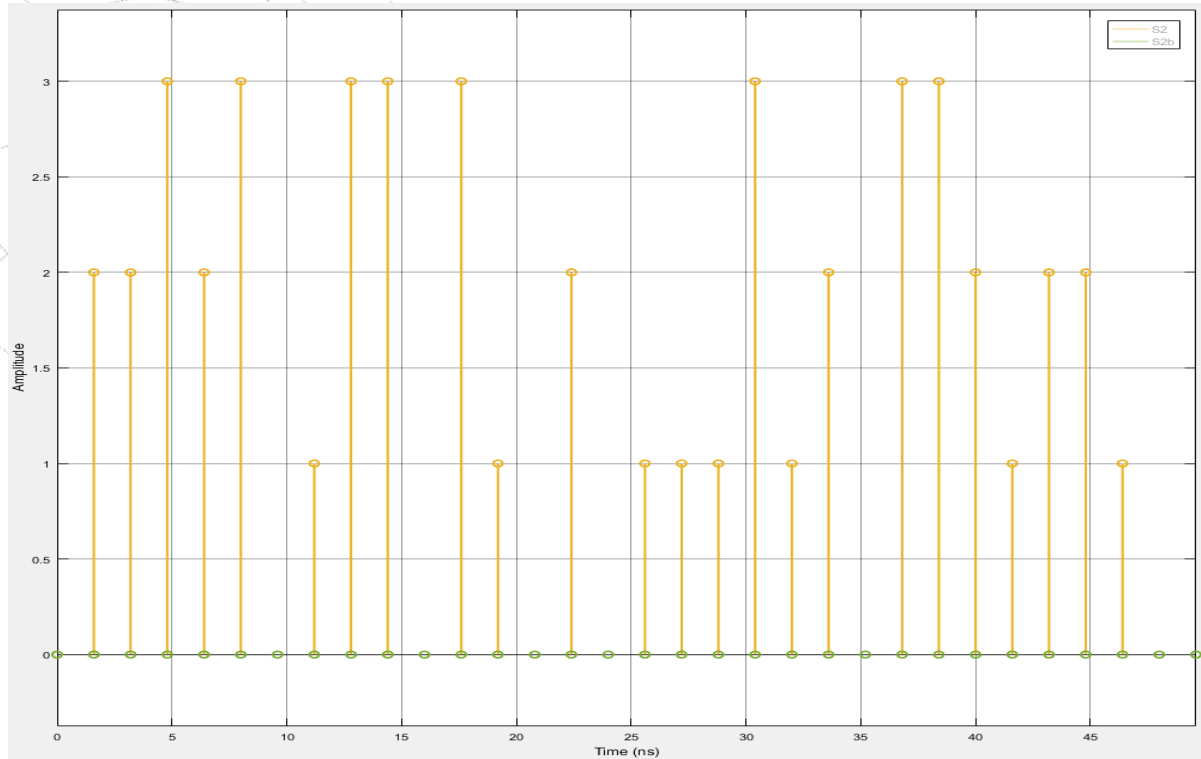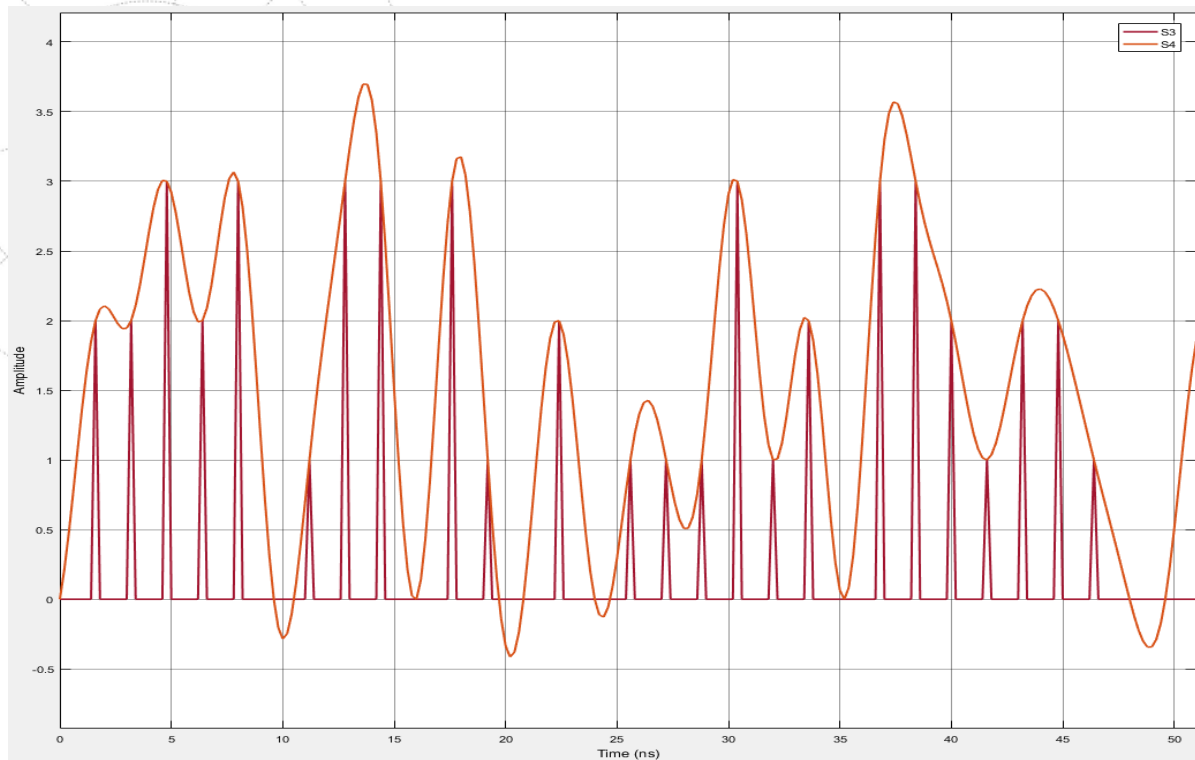
Simulation setup

- **Transmitter setup**
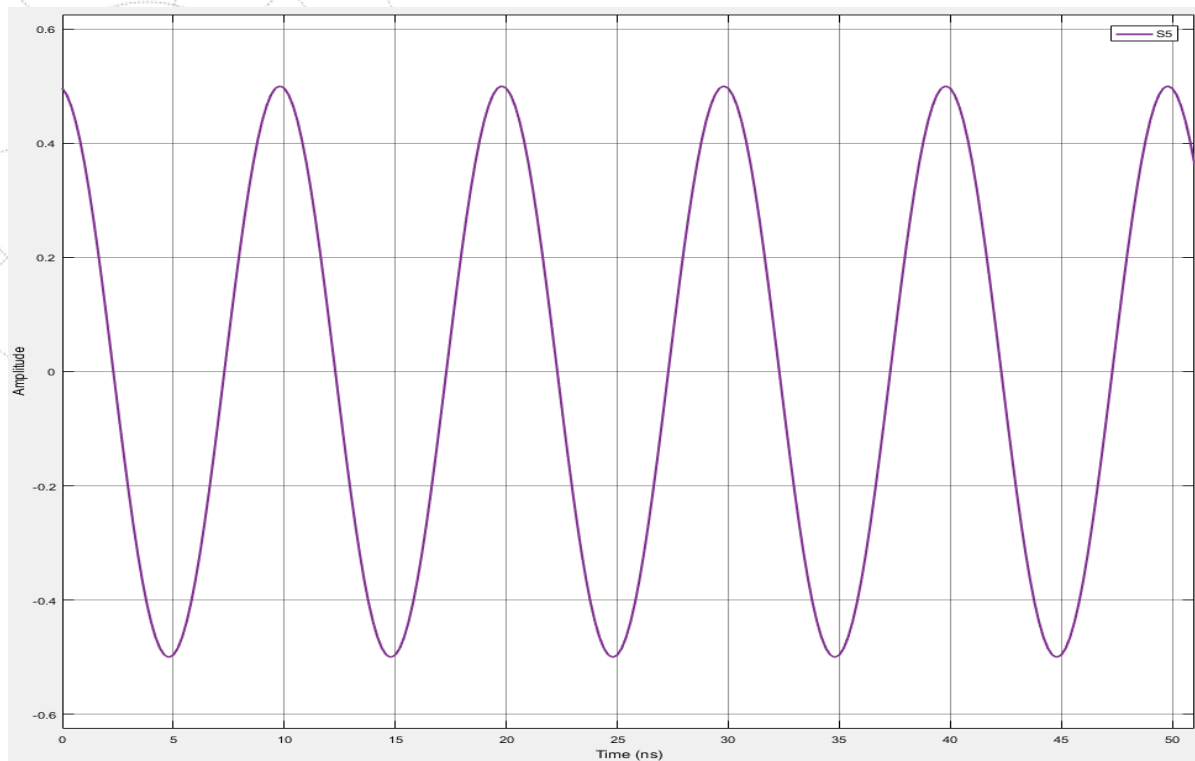

Transmitter simulation setup

Simulation Results

S2 and S2b signals

S3 S4 signals

S5 signal
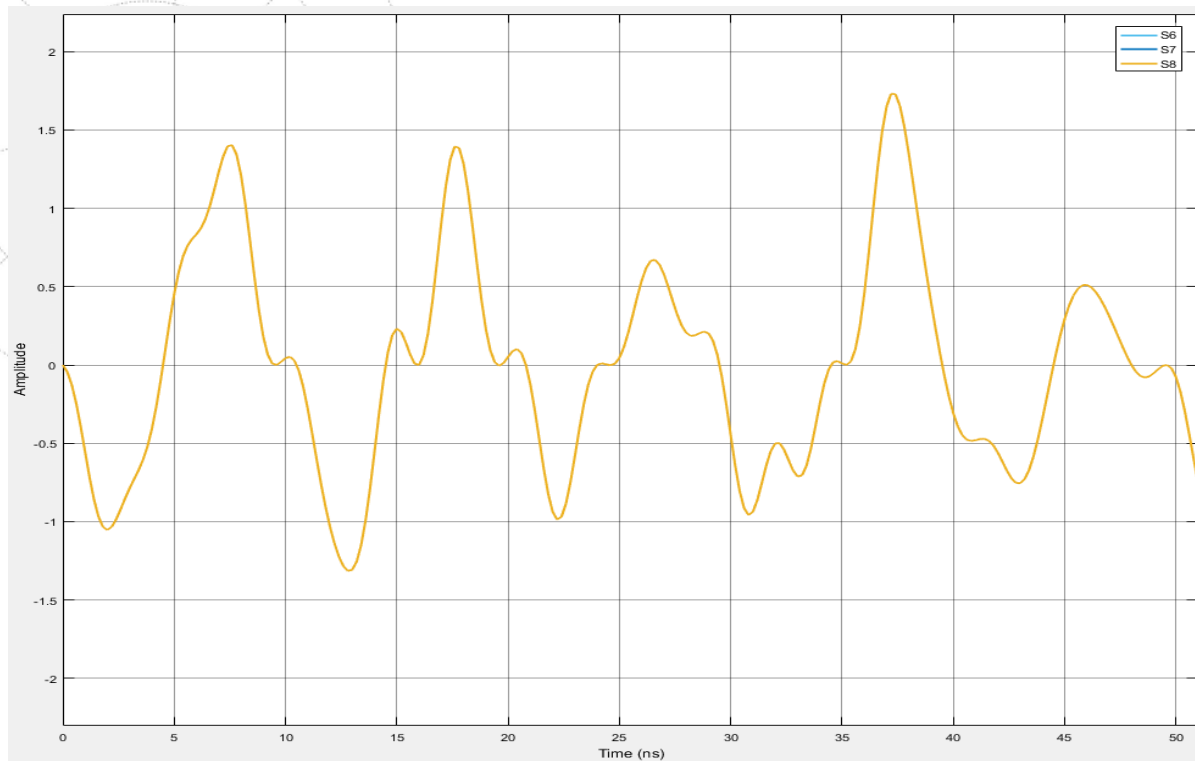
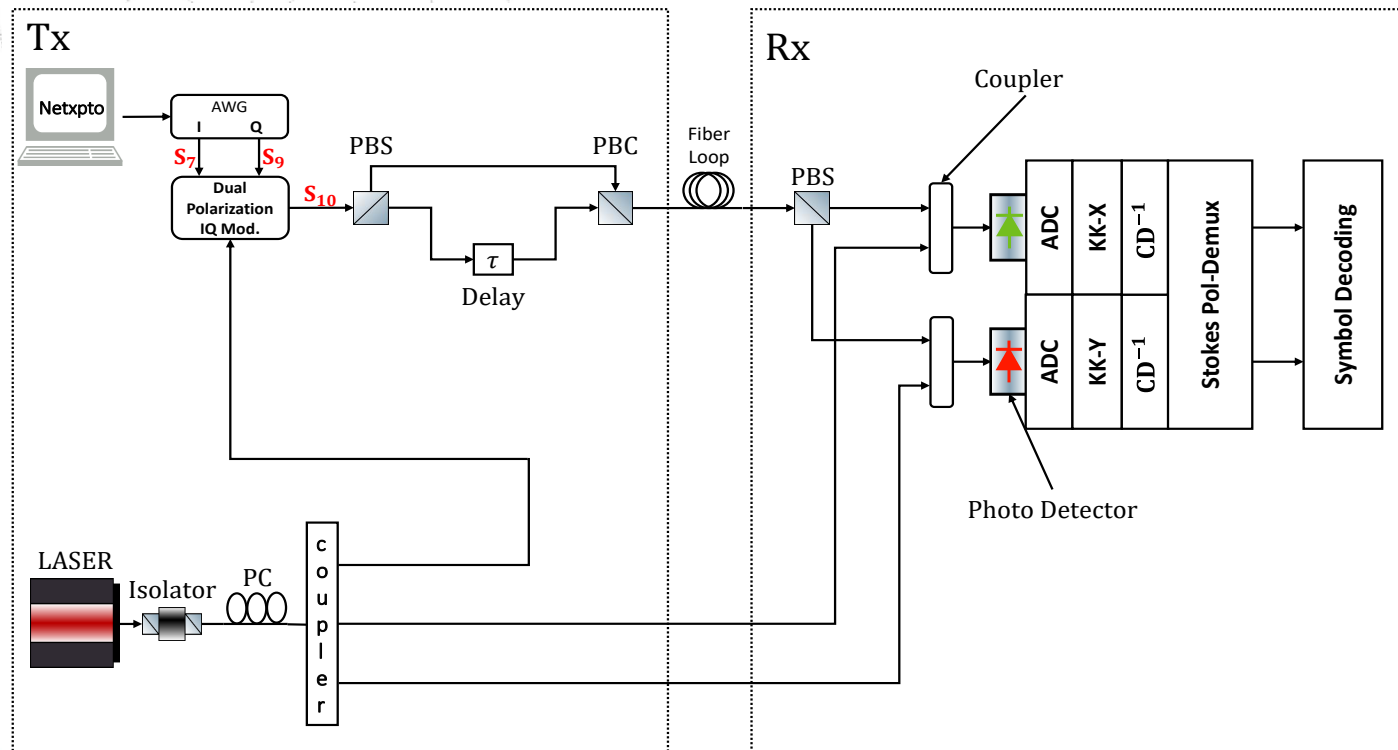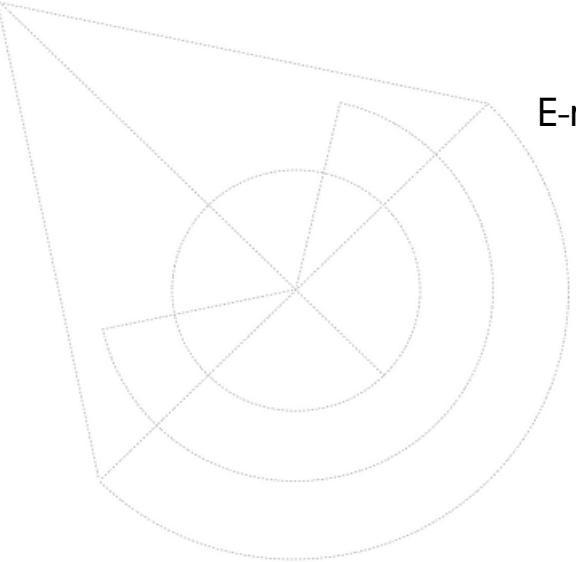S6, S7 and S8 signals

Experimental setup

- ## Envisioned lab setup

Tx

Netxpto

AWG
I   Q

S_7 S_9

Dual Polarization IQ Mod.

S_{10}

PBS

Delay τ

PBC

Fiber Loop

LASER

Isolator   PC   coupler

Rx

Coupler

PBS

Photo Detector

ADC | KK-X | CD^{-1} | Stokes Pol-Demux | Symbol Decoding

ADC | KK-Y | CD^{-1}

PDM Kramers-Kronig receiver experimental setup

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