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Simplified Coherent Transceivers for Optical Communication Networks

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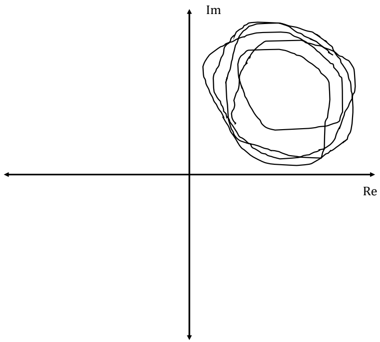
Theocratical Overview

- 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 $t \in (-\infty, \infty)$.

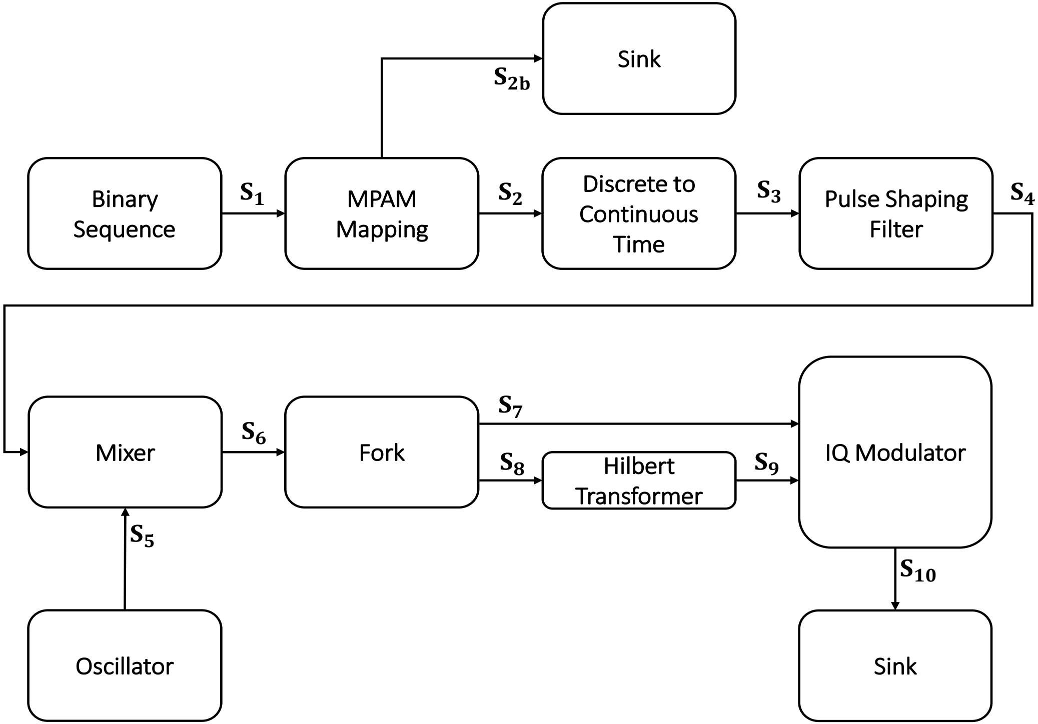
$$G(t) = ln\left[\frac{A(t)}{\bar{A}}\right] \quad (3)$$

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

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

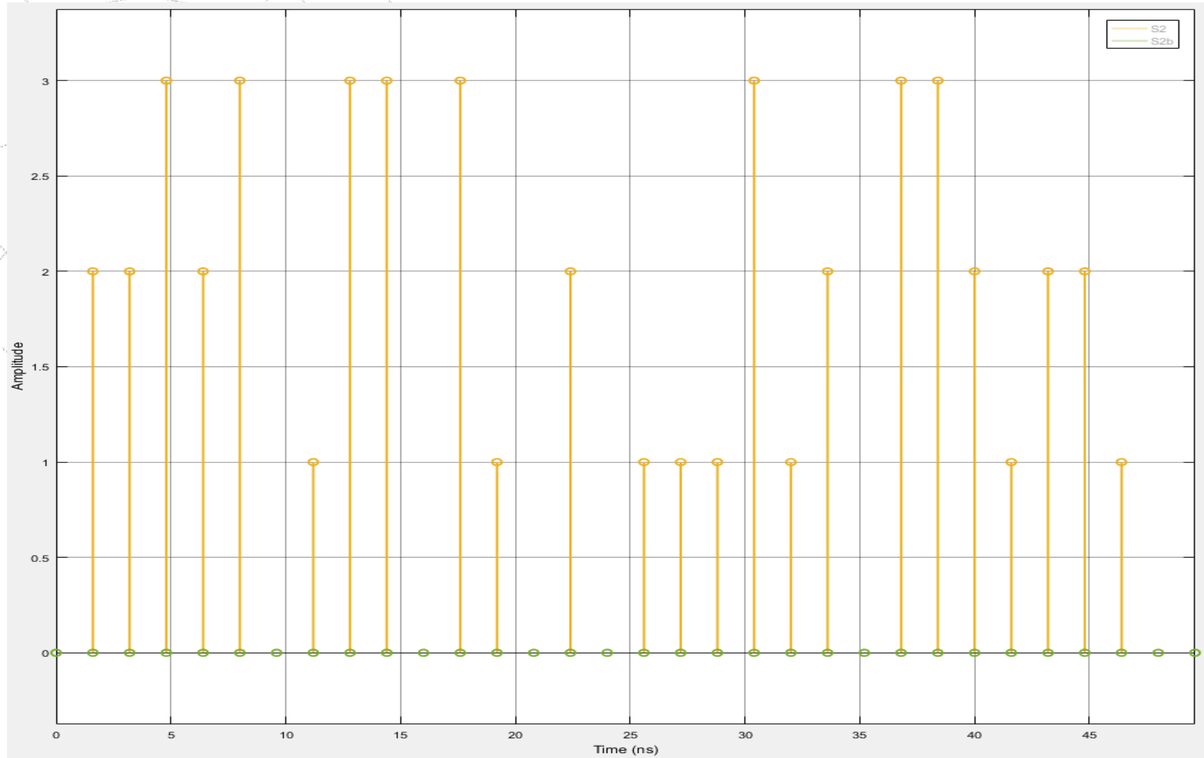
Simulation setup

- **Transmitter setup**

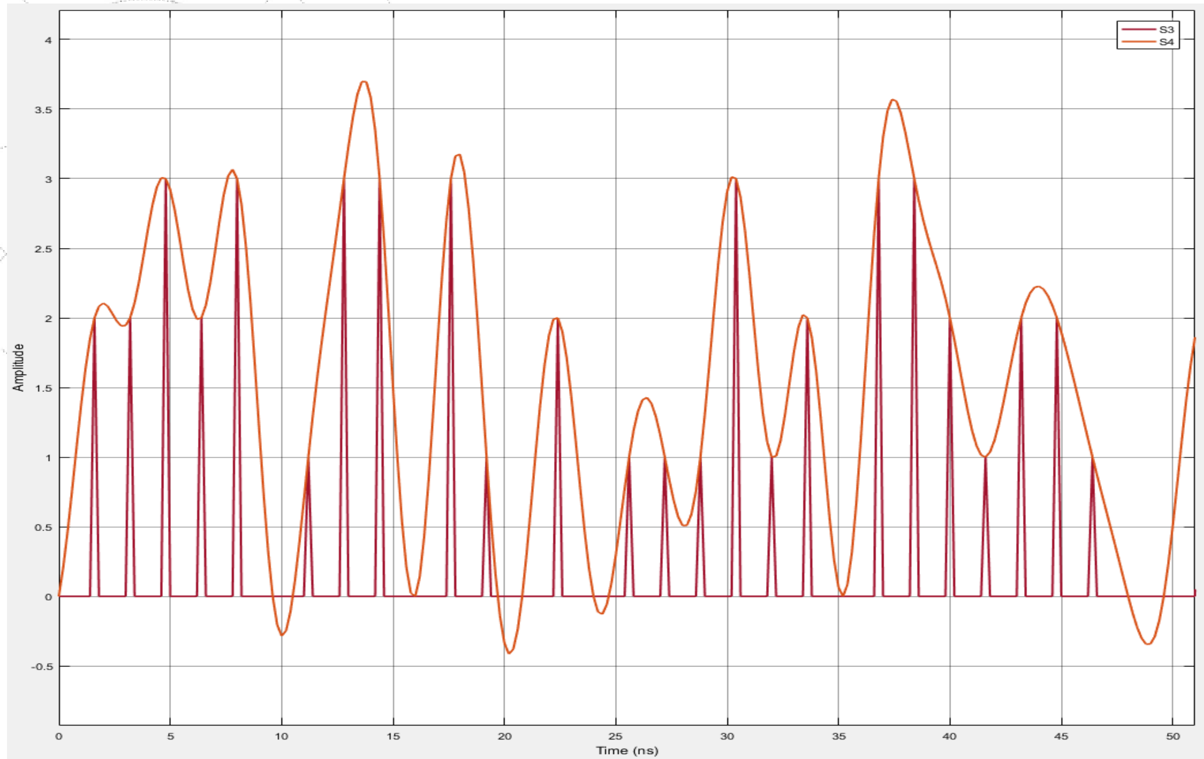


Transmitter simulation setup

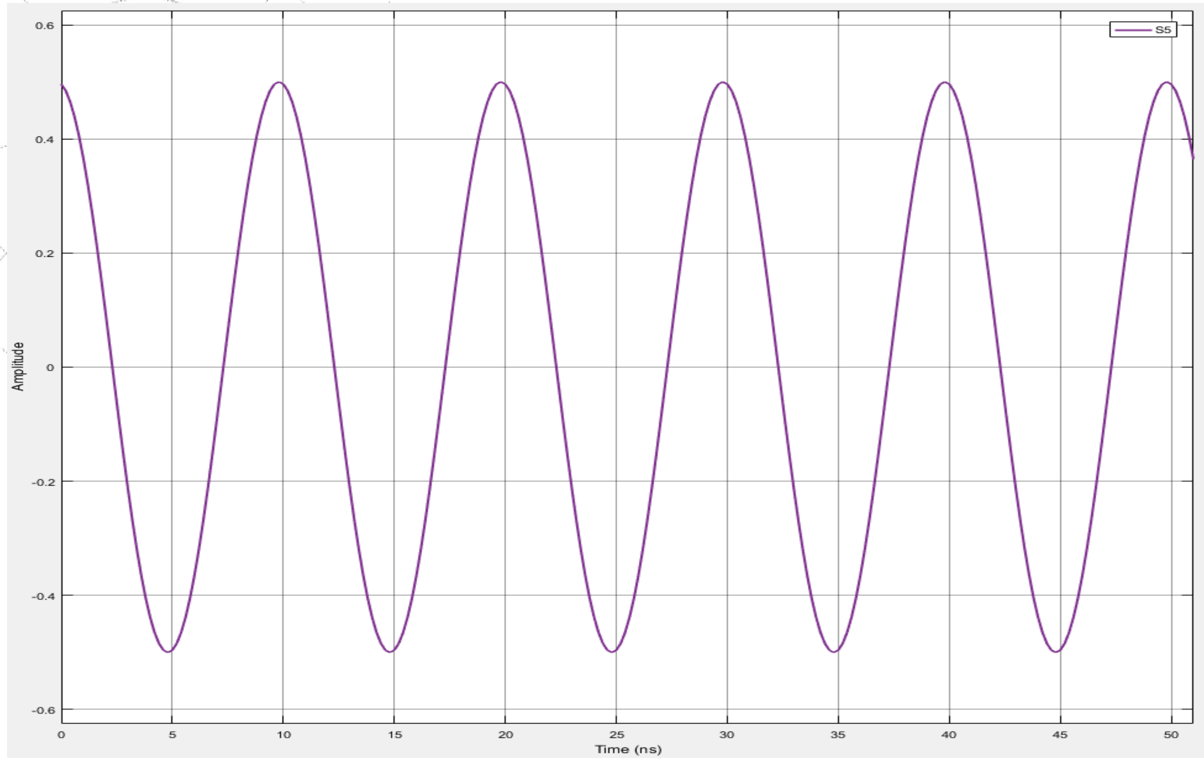
Simulation Results



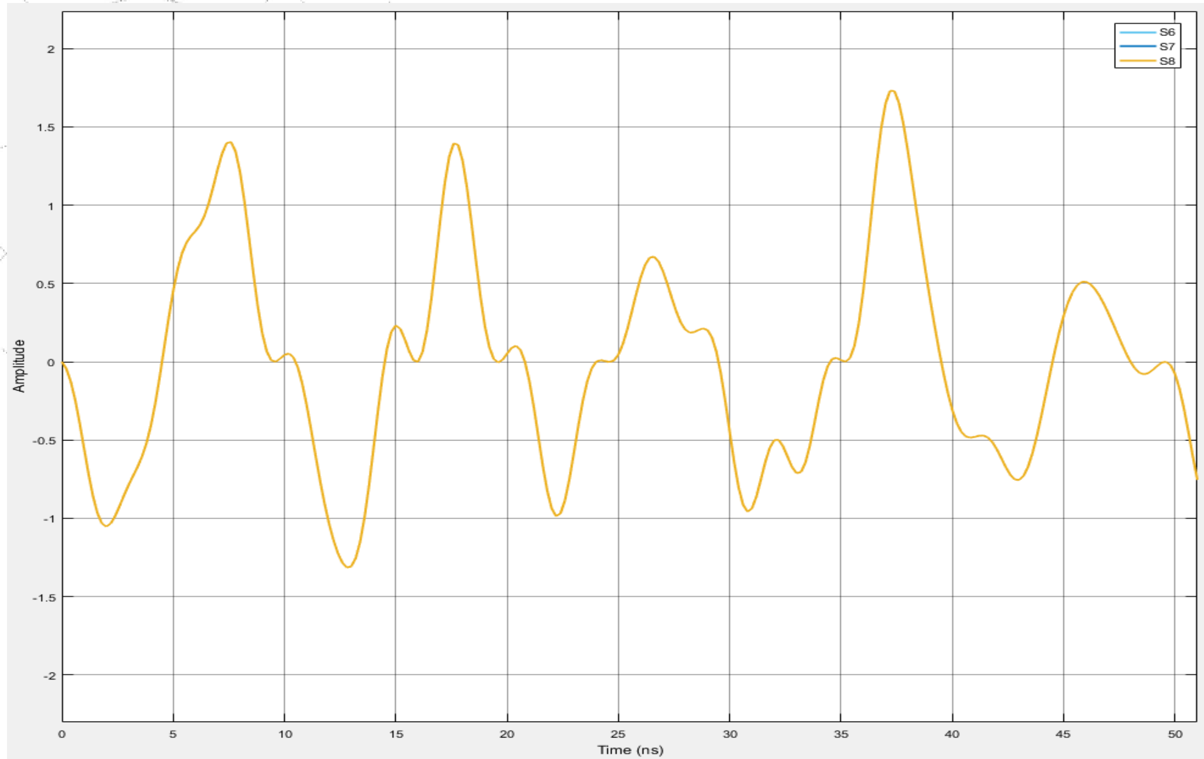
S2 and S2b signals



S3 S4 signals


0.6
0.4
0.2
0
-0.2
-0.4
-0.6
Amplitude
0
5
10
15
20
25
30
35
40
45
50
Time (ns)
S5

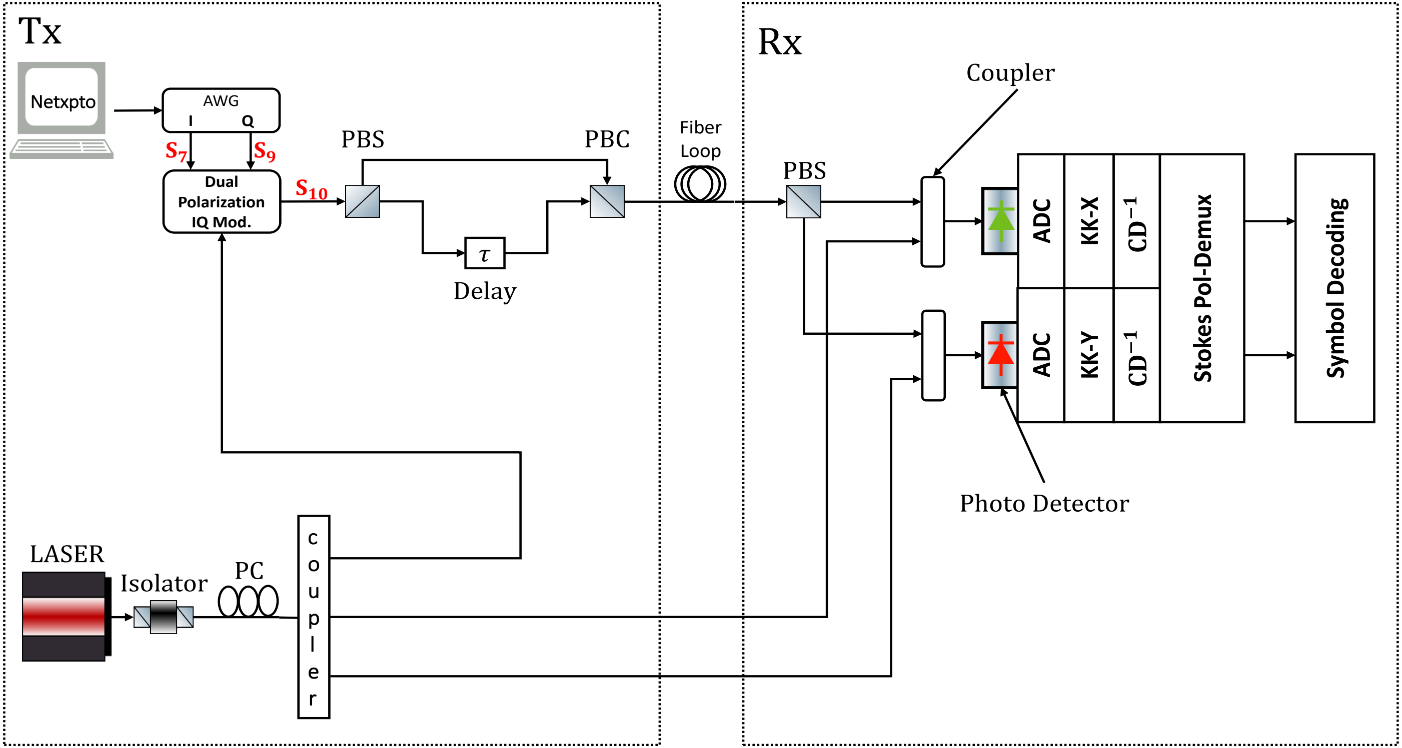
S5 signal



S6, S7 and S8 signals

Experimental setup

- **Envisioned lab setup**



PDM Kramers-Kronig receiver experimental setup

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