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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, in which phase can be uniquely extracted from its intensity.
- The following few slides would give a comprehensive overview about the working principle Kramers-Kronig receiver.

Requirement of Kramers-Kronig scheme

By definition, the SSB is the signal which contains either upper sideband or lower sideband and hence it reduces the spectral occupancy by half. In another words, SSB signal is the frequency translated version of an analytical signal.

- **Analytical Signal** : An analytic signal is a complex-valued signal that has no negative frequency components, and its real and imaginary parts are related to each other by the Hilbert transform.

$$s_a(t) = s(t) + i\hat{s}(t) \tag{1}$$

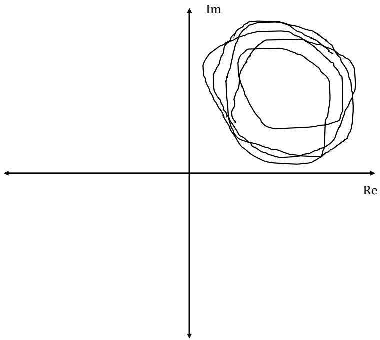
where, $s_a(t)$ is an analytical signal and $\hat{s}(t)$ is the Hilbert transform of the signal $s(t)$. Such analytical signal can be used to generate Single Sideband Signal (SSB) signal.

Since a SSB signal is the frequency translated version of an analytical signal, it can be generated as,

$$
\begin{aligned}
s_{ssb}(t) &= Re\{s_a(t)e^{i2\pi f_0 t}\} \\
&= Re\{[s(t) + i\hat{s}(t)][cos(2\pi f_0 t) + isin(2\pi f_0 t)]\} \\
&= s(t)cos(2\pi f_0 t) - \hat{s}(t)sin(2\pi f_0 t)
\end{aligned} \tag{2}
$$

3. What is minimum phase signal?

- A necessary and sufficient condition for a complex signal $A(t)$ 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**.
- A minimum-phase signal has an useful property that the natural logarithm of the magnitude of the frequency response is related to the phase angle of the frequency response by the Hilbert transform.



Minumum Phase Signal

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

- **Analytical Signal:**
  If we denote an analytic signal $A_s(t)$ as,

$$A_s(t) = A_{s,r}(t) + iA_{s,i}(t) \tag{3}$$

then in the equation 3, 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,

$$\begin{aligned} A_{s,r}(t) &= -\frac{1}{\pi} p.v. \int_{-\infty}^{\infty} \frac{A_{s,i}(t')}{t-t'} dt' \\ A_{s,i}(t) &= \frac{1}{\pi} p.v. \int_{-\infty}^{\infty} \frac{A_{s,r}(t')}{t-t'} dt' \end{aligned} \tag{4}$$

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

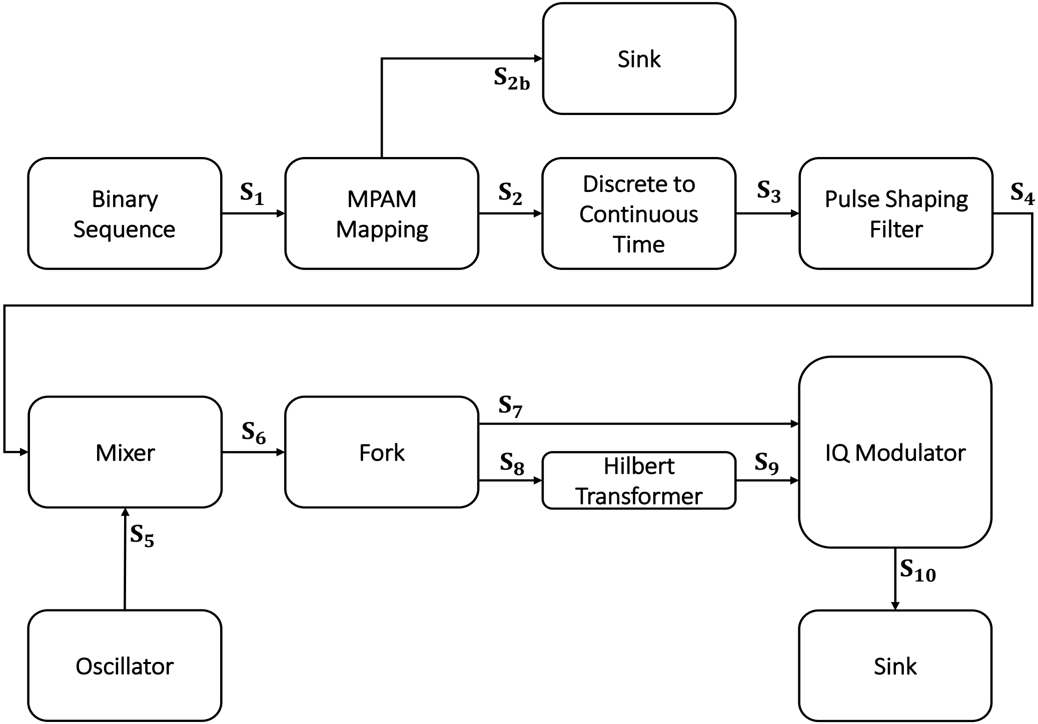
$$G(t) = log\left[\frac{A(t)}{\bar{A}}\right] \tag{5}$$

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

.
$$\phi(t) = \bar{\phi} + \frac{1}{2\pi} p.v. \int_{-\infty}^{\infty} \frac{log|A(t)|^2}{t-t'} dt' \tag{6}$$

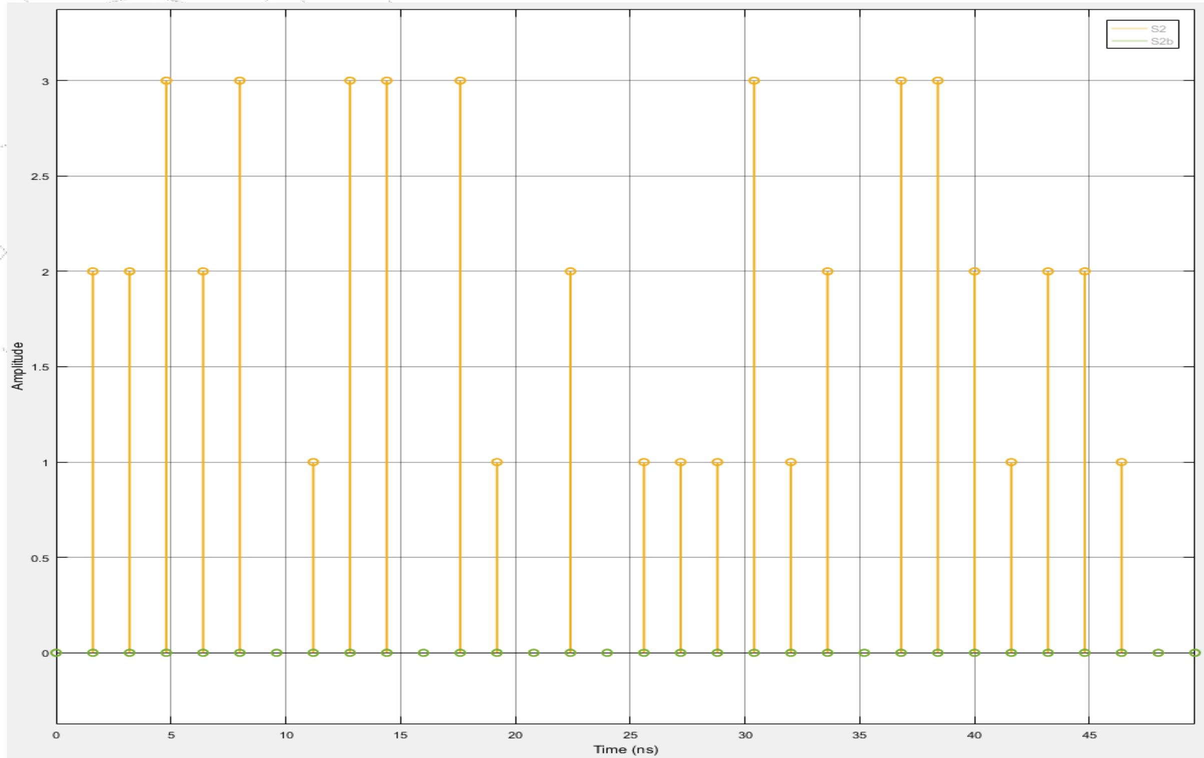
Simulation setup

- **Transmitter setup**

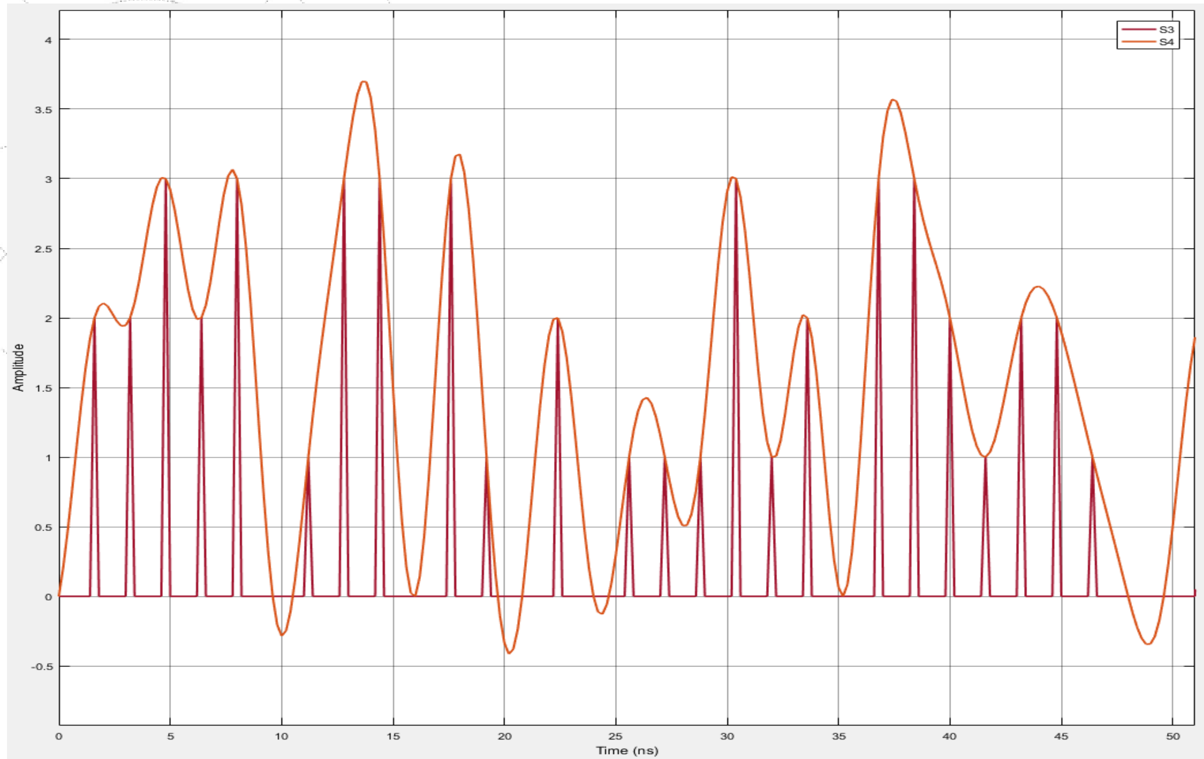


Transmitter simulation setup

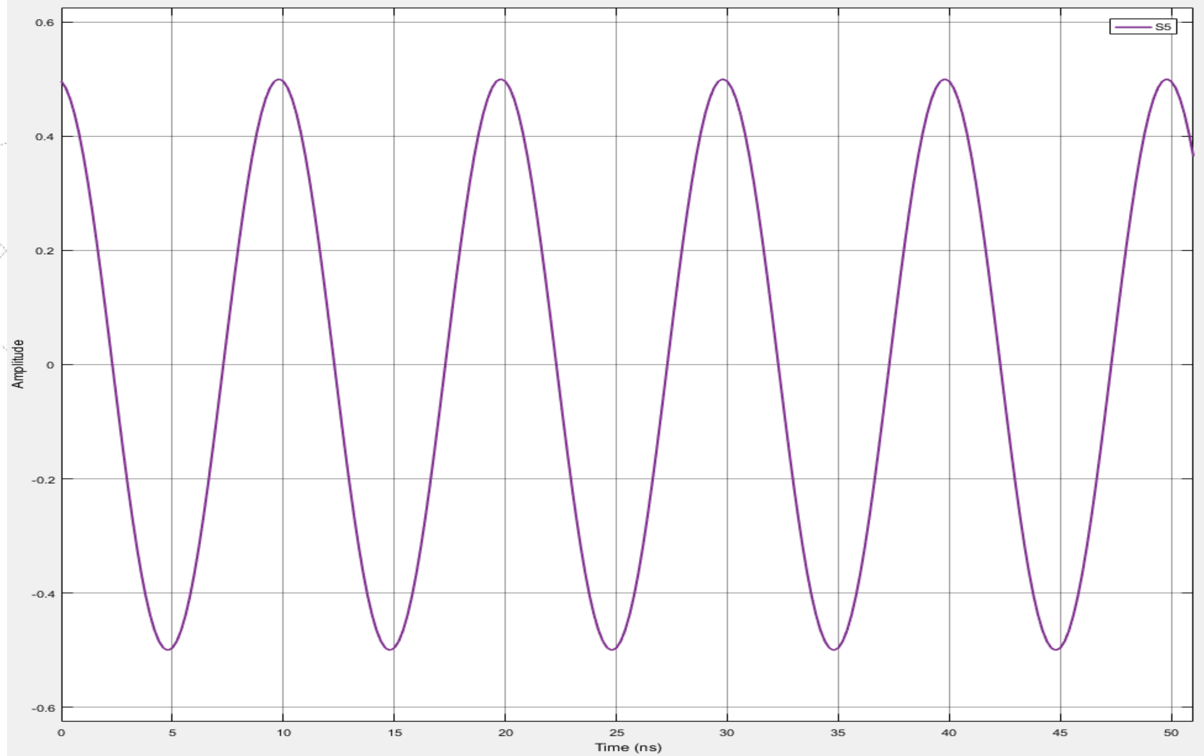
Simulation Results



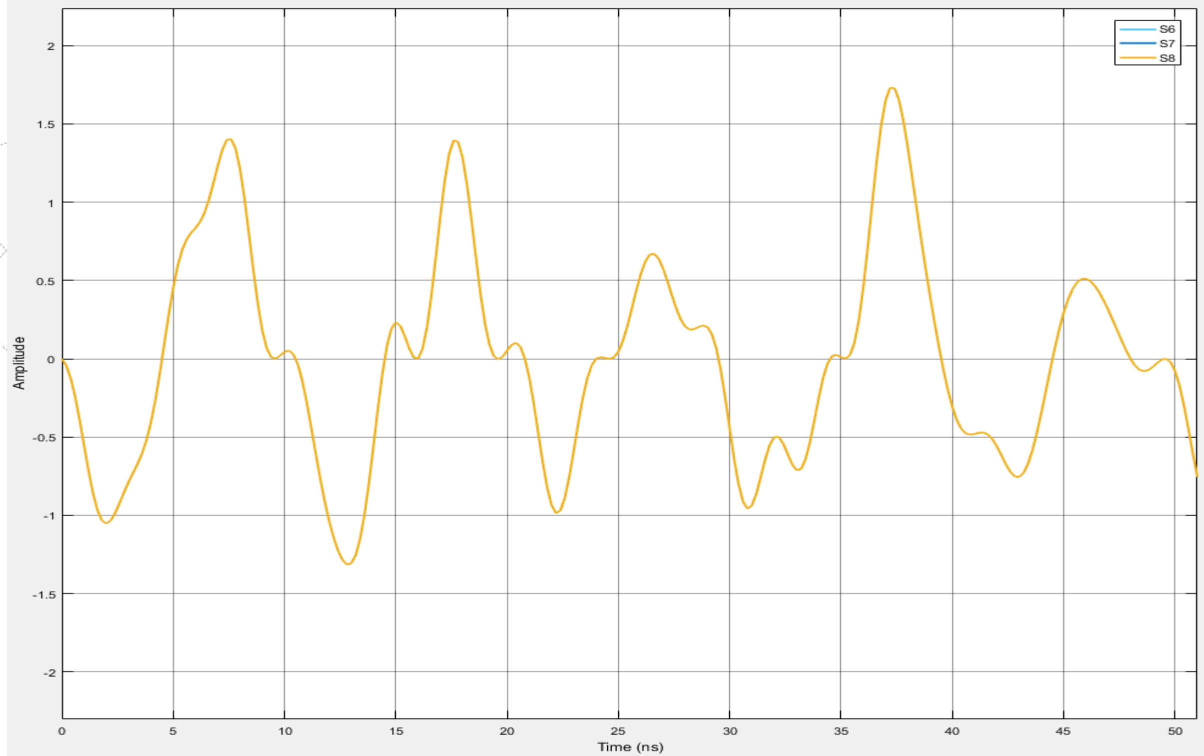
S2 and S2b signals



S3 S4 signals


S5
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)

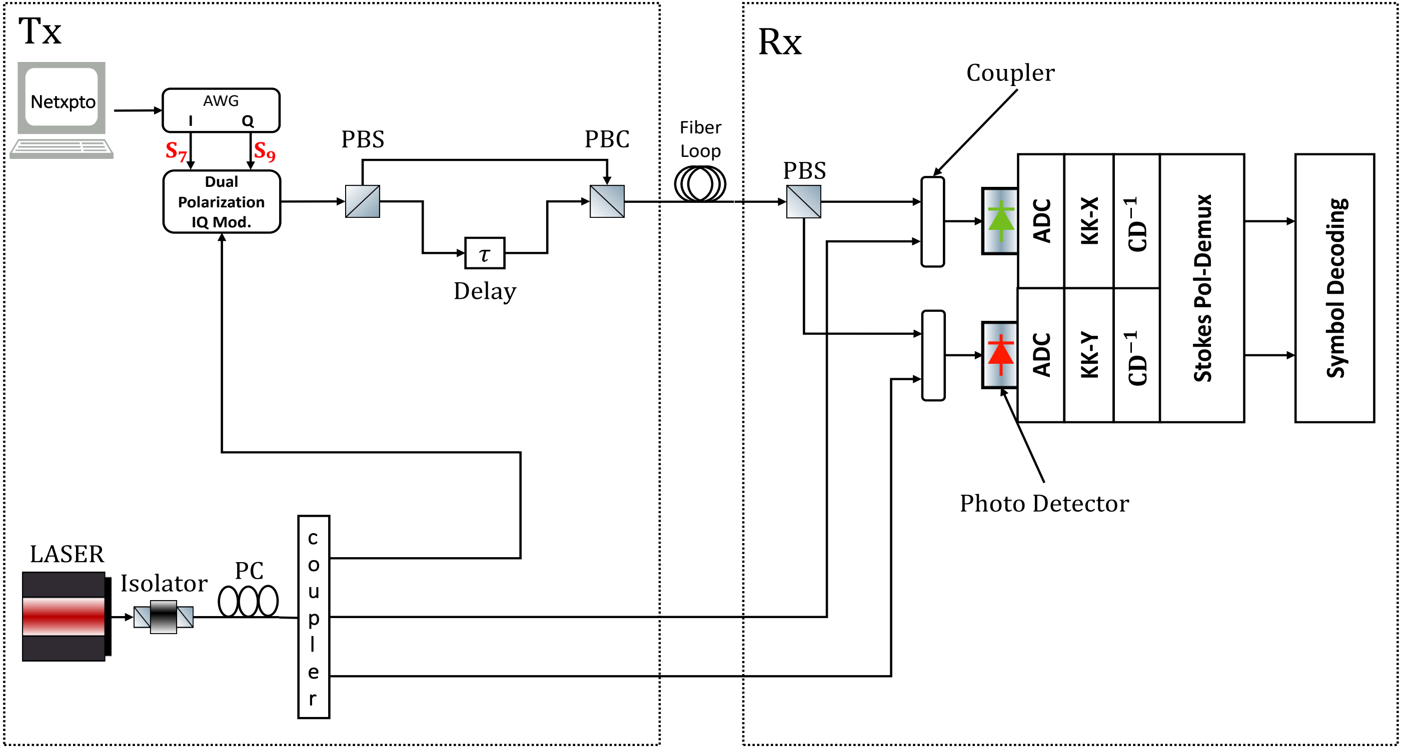
S5 signal



S6, S7 and S8 signals

Experimental setup

- **Envisioned lab setup**



PDM Kramers-Kronig receiver experimental setup

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