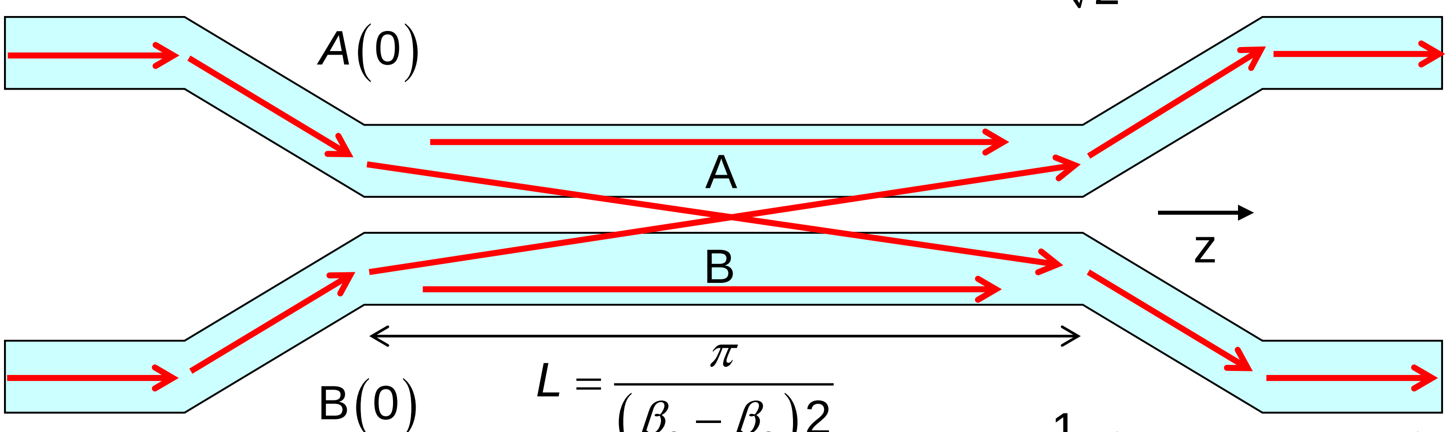
90 Degree Optical Hybrid

$$\begin{bmatrix} A(L) \\ \mathrm{B}(L) \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{2}} & -j\frac{1}{\sqrt{2}} \\ -j\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} A(0) \\ B(0) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -j \\ -j & 1 \end{bmatrix} \begin{bmatrix} A(0) \\ B(0) \end{bmatrix}$$

$$A(L) = \frac{1}{\sqrt{2}}\left(A(0) - jB(0)\right)$$



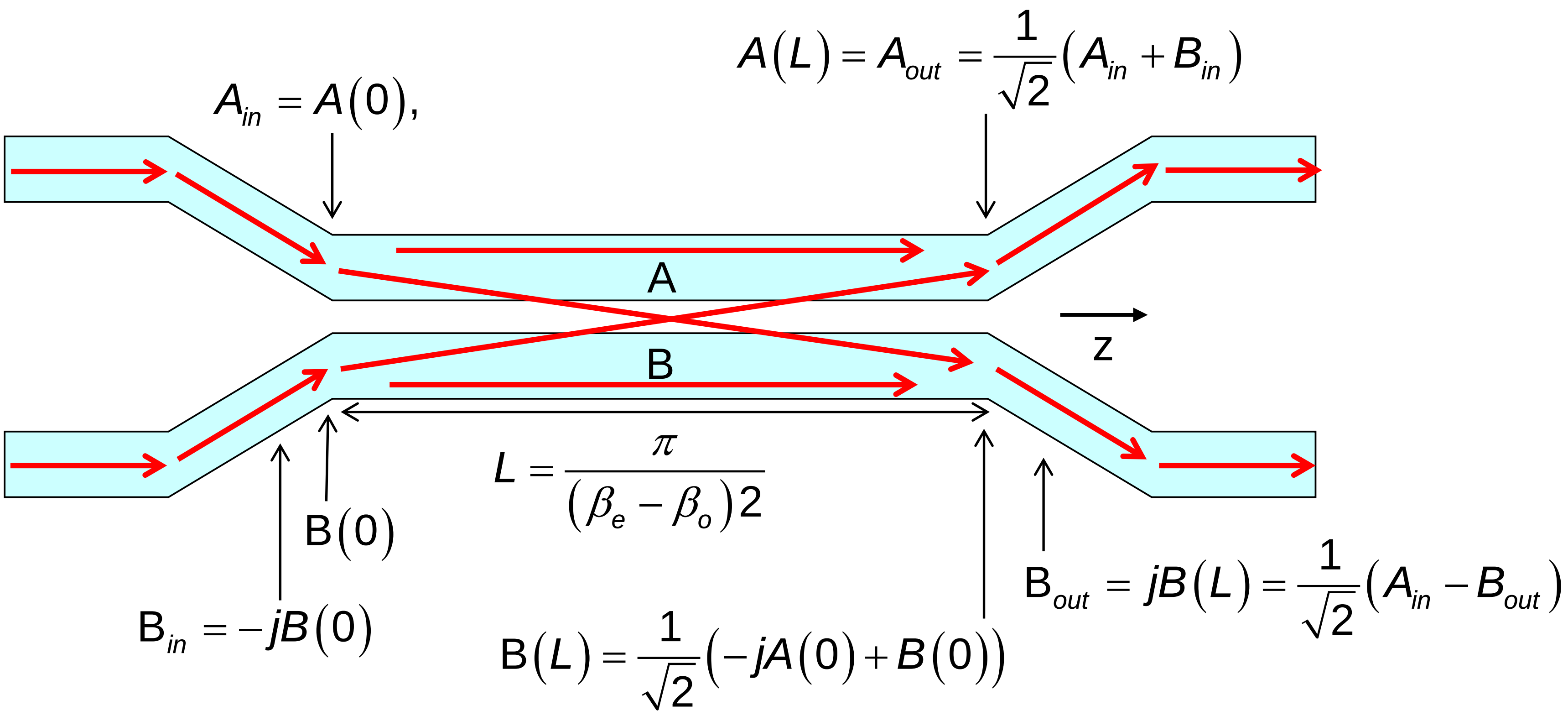
$$L = \frac{\pi}{(\beta_e - \beta_o)2}$$

$$\mathrm{B}(L) = \frac{1}{\sqrt{2}}\left(-jA(0) + B(0)\right)$$

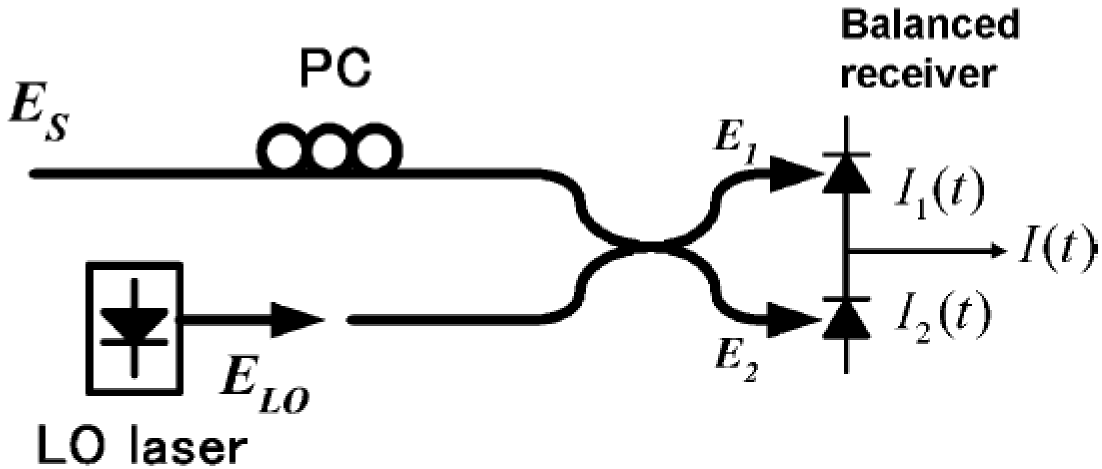
90 Degree Optical Hybrid

Redefining the phase for input and output arms, we can write:

$$\begin{bmatrix} A_{out} \\ B_{out} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} A_{in} \\ B_{in} \end{bmatrix}$$



Coherent Detection



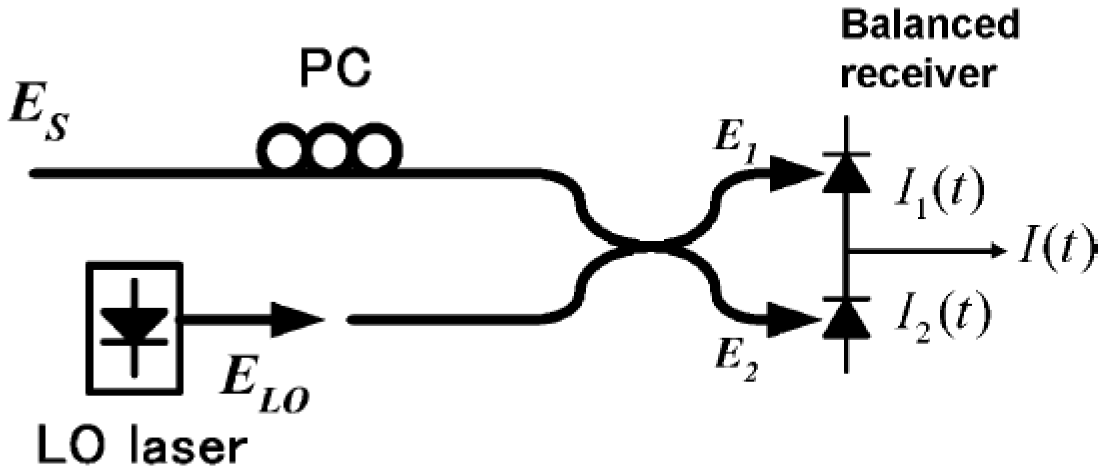
$$E_s(t) = A_s(t)\exp(j\omega_s t)$$

$$E_{LO}(t) = A_{LO}\exp(j\omega_{LO} t)$$

$$P_S = |A_S|^2/2 \text{ and } P_{LO} = |A_{LO}|^2/2$$

From "Coherent Optical Communications: Historical Perspectives and Future Directions," by Kazuro Kikuchi, Chapter 2 in *High Spectral Density Optical Communications*, Nakazawa et al. editors.

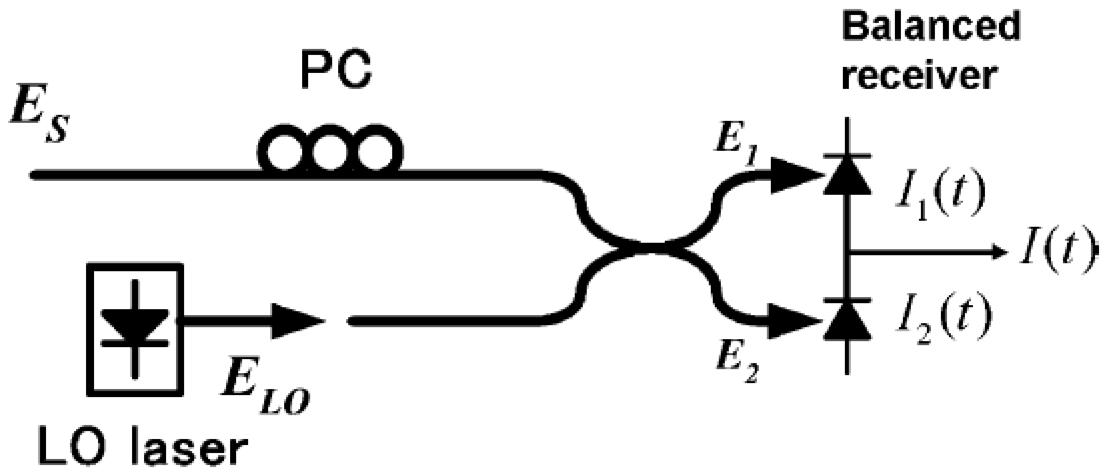
Coherent Detection



$$E_1 = \frac{1}{\sqrt{2}}\left(E_S + E_{LO}\right)$$

$$E_2 = \frac{1}{\sqrt{2}}\left(E_S - E_{LO}\right)$$

Coherent Detection



$$I_1(t) = R\left[\mathrm{Re}\left\{\frac{A_S(t)\exp(j\omega_S t) + A_{LO}\exp(j\omega_{LO} t)}{\sqrt{2}}\right\}\right]^{ms}$$

$$= \frac{R}{2}\left[P_S(t) + P_{LO} + 2\sqrt{P_s(t)P_{LO}}\cos\left\{\omega_{IF} t + \theta_{sig}(t) - \theta_{LO}(t)\right\}\right]$$

$$R = \frac{e\eta}{\hbar\omega_S}$$

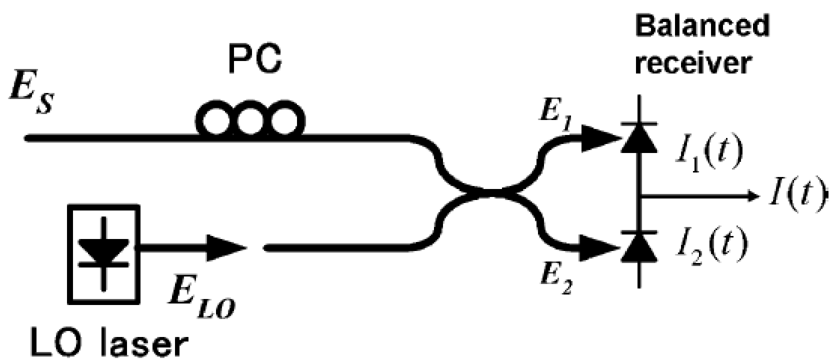
$$I_2(t) = R\left[\mathrm{Re}\left\{\frac{A_S(t)\exp(j\omega_S t) - A_{LO}\exp(j\omega_{LO} t)}{\sqrt{2}}\right\}\right]^{ms}$$

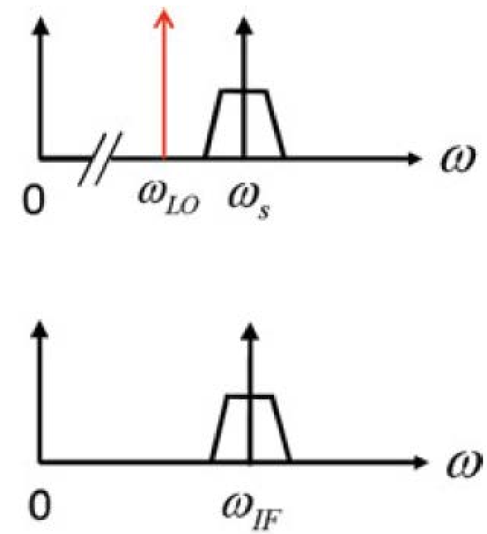
$$\theta_{sig} = \theta_s + \theta_n$$

$$\omega_{IF} = \omega_s - \omega_{LO}$$

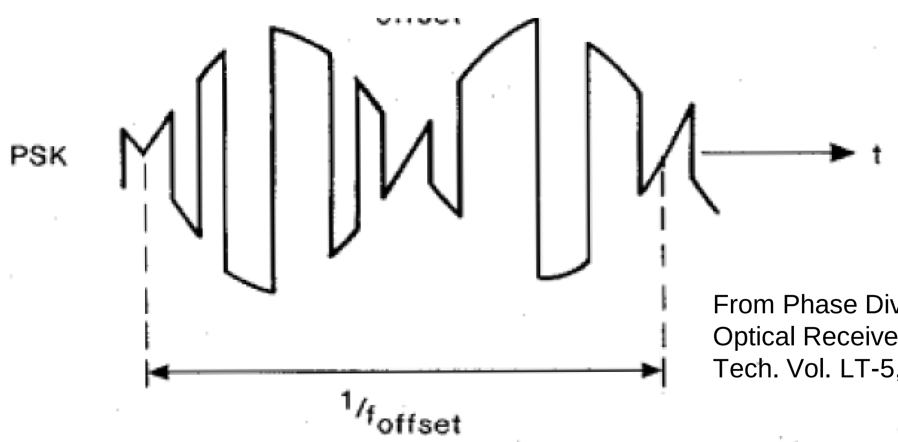
$$= \frac{R}{2}\left[P_S(t) + P_{LO} - 2\sqrt{P_s(t)P_{LO}}\cos\left\{\omega_{IF} t + \theta_{sig}(t) - \theta_{LO}(t)\right\}\right]$$

Down-Converted Signal





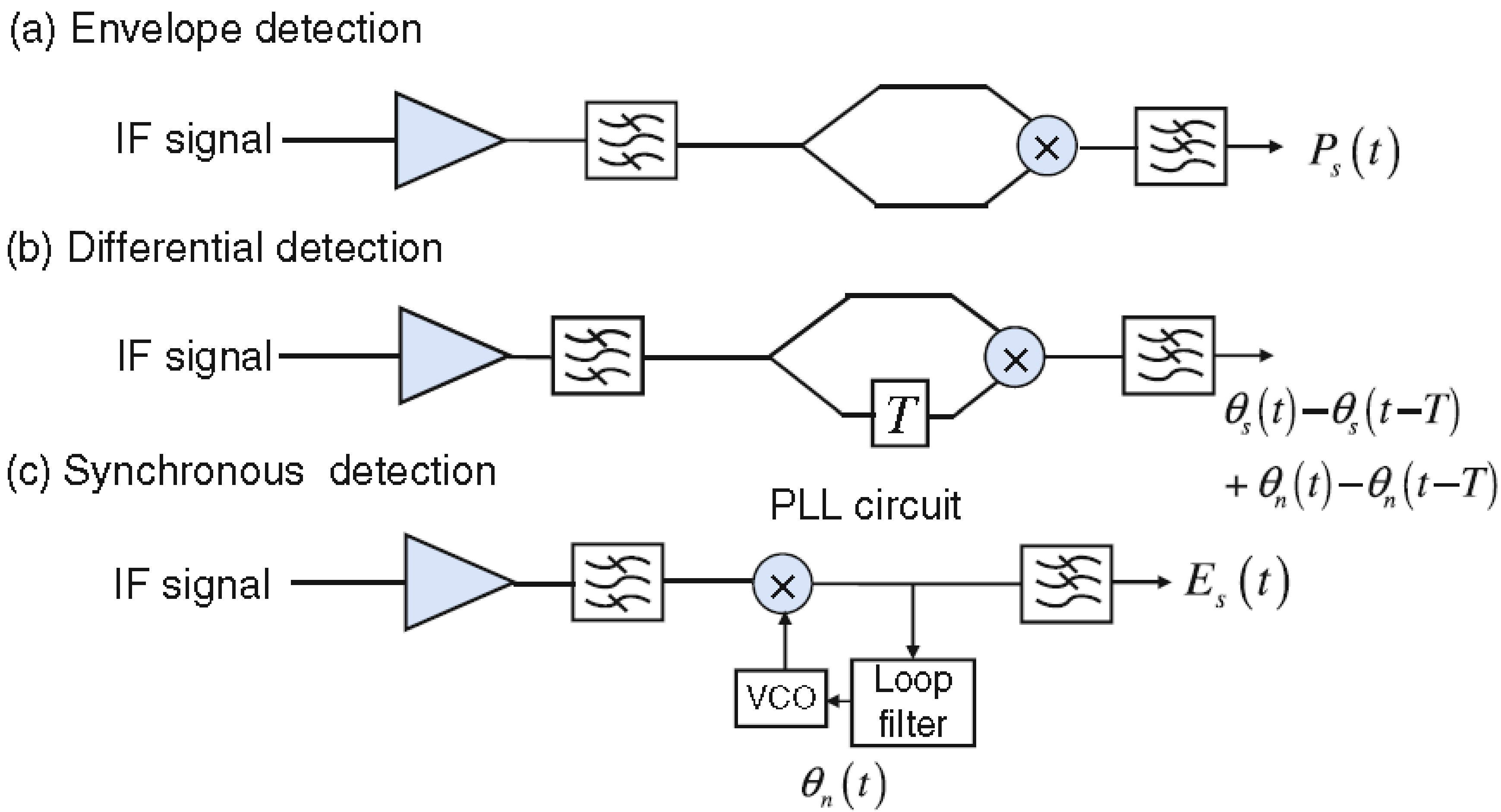
$$\omega_{IF} = |\omega_s - \omega_{LO}|$$



From Phase Diversity Techniques for Coherent Optical Receivers, Davis et al., J. of Lightwave Tech. Vol. LT-5, p. 561 (1987)

$$I(t) = I_1(t) - I_2(t) = 2R\sqrt{P_s(t)P_{LO}}\cos\{\omega_{IF}t + \theta_{sig}(t) - \theta_{LO}(t)\}$$

Demodulating the IF Signal



Demodulating the IF Signal

We have three methods of demodulating $I_c(t)$, which are envelope (noncoherent) detection, differential (delay) detection, and synchronous (coherent) detection as shown in Fig. 2.13. In envelope detection, we measure $|I_c(t)|^2$ from Eq. (2.10), which gives us only the information on $P_s(t)$. Differential detection is effective for constant-envelope modulation formats such as M-ary PSK. In this scheme, we determine the phase difference between the current symbol and the previous one. In the synchronous detection scheme, although the total phase noise $\theta_n(t) = \theta_{sn}(t) - \theta_{\mathrm{LO}}(t)$ might vary in time, the electrical phase-locked loop (PLL) can be used to estimate the phase noise and decode the symbol.