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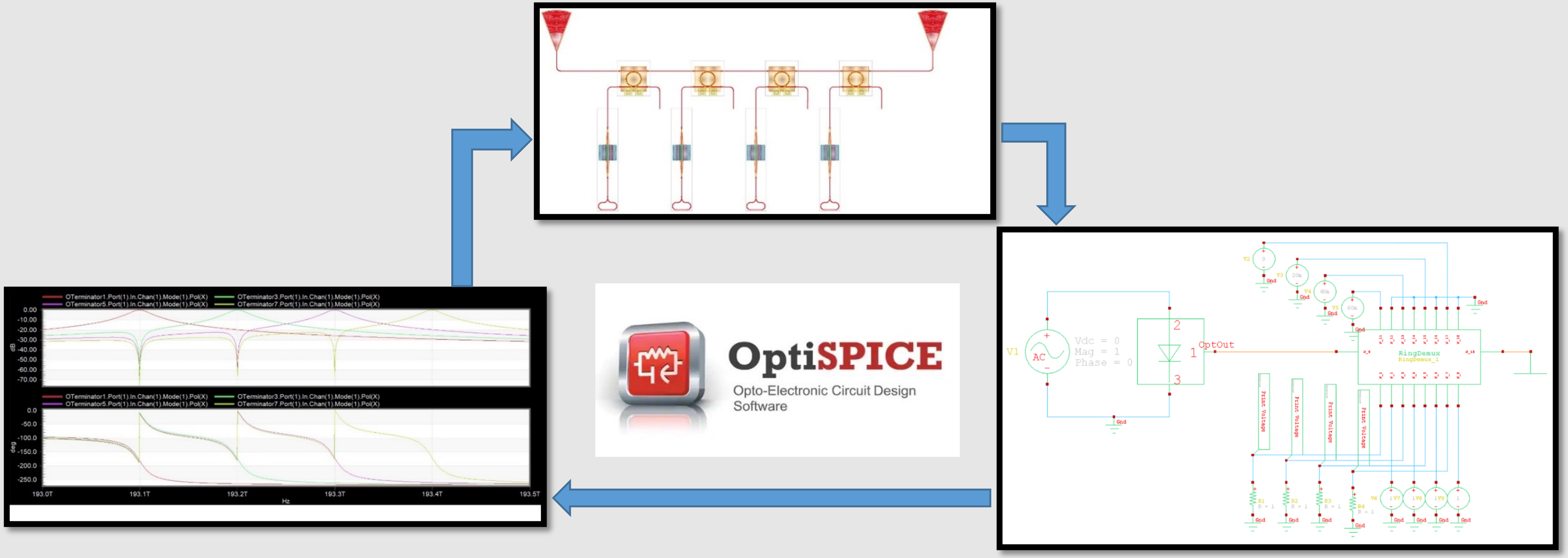


BPSK Coherent Demodulation Using Ligentec PDK Building Blocks

7 Capella Court
Nepean, ON, Canada
K2E 7X1

+1 (613)- 224-4700
www.optiwave.com

Background of the Application Example

- In the high speed Digital Signal Processing (DSP), coherent detection technique is used in complex quasi-monochromatic fields modulated Digital Subcarrier Multiplexed (DSCM) systems.

- This document specifically demonstrates MUX & De-MUX of two channels in the DSCM systems using coherent detection.

- For simplicity, the following processes are not shown:
  - Within transmitter:
    - Digital processing of the transmitted signal
    - Conversion of digital signal to analog signal
  - Within receiver:
    - Analog to digital conversion of the In-phase and Quadrature component
    - Processing of digital signal to recover data
    - Polarization maintenance of signal in receiver

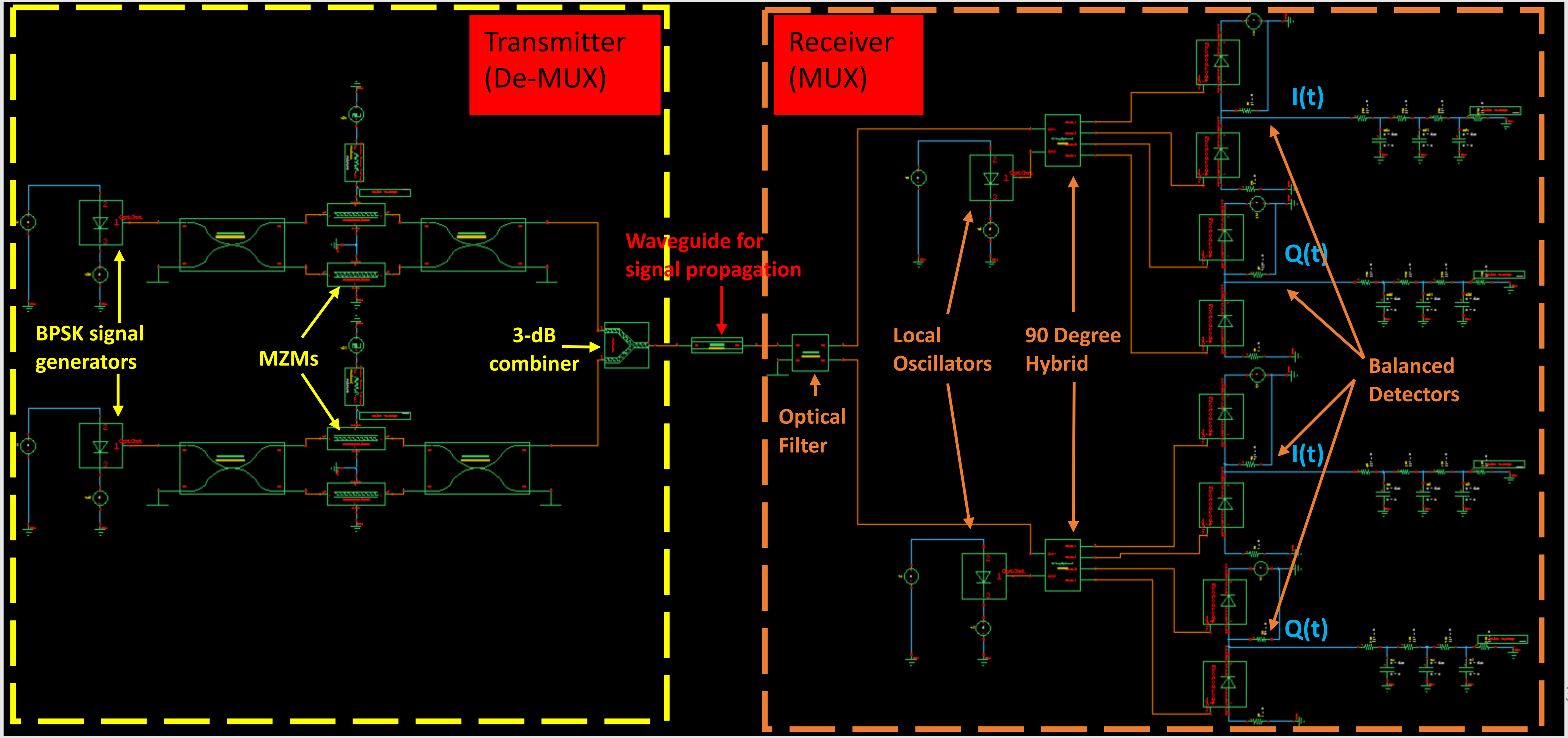
- Circuits comprises of building blocks from the PDK of Ligentec foundry and the elements of OptiSPICE library.

- The Ligentec PDK devices are modelled within the Siemens Tanner S-edit tool using OptiSPICE plugin API.

- The entire circuit is build and simulated in Tanner S-edit.

BPSK Coherent Detection Demodulator Building Blocks

- Transmitter:
  - Two BPSK signal generators
  - Two Mach Zehnder Modulators
  - 3-dB combiner
- Receiver:
  - Optical filter
  - Two local oscillators
  - Two 90 degree hybrid
  - Four balanced detectors



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Transmitter Building Blocks

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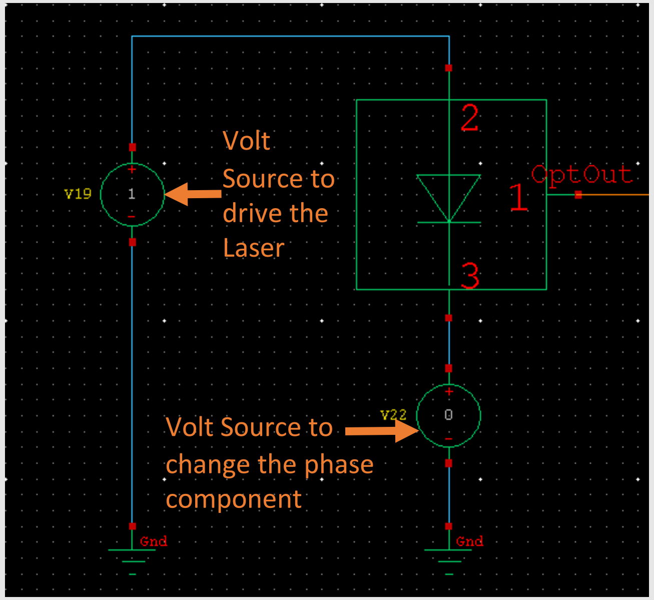
BPSK Signal Generator

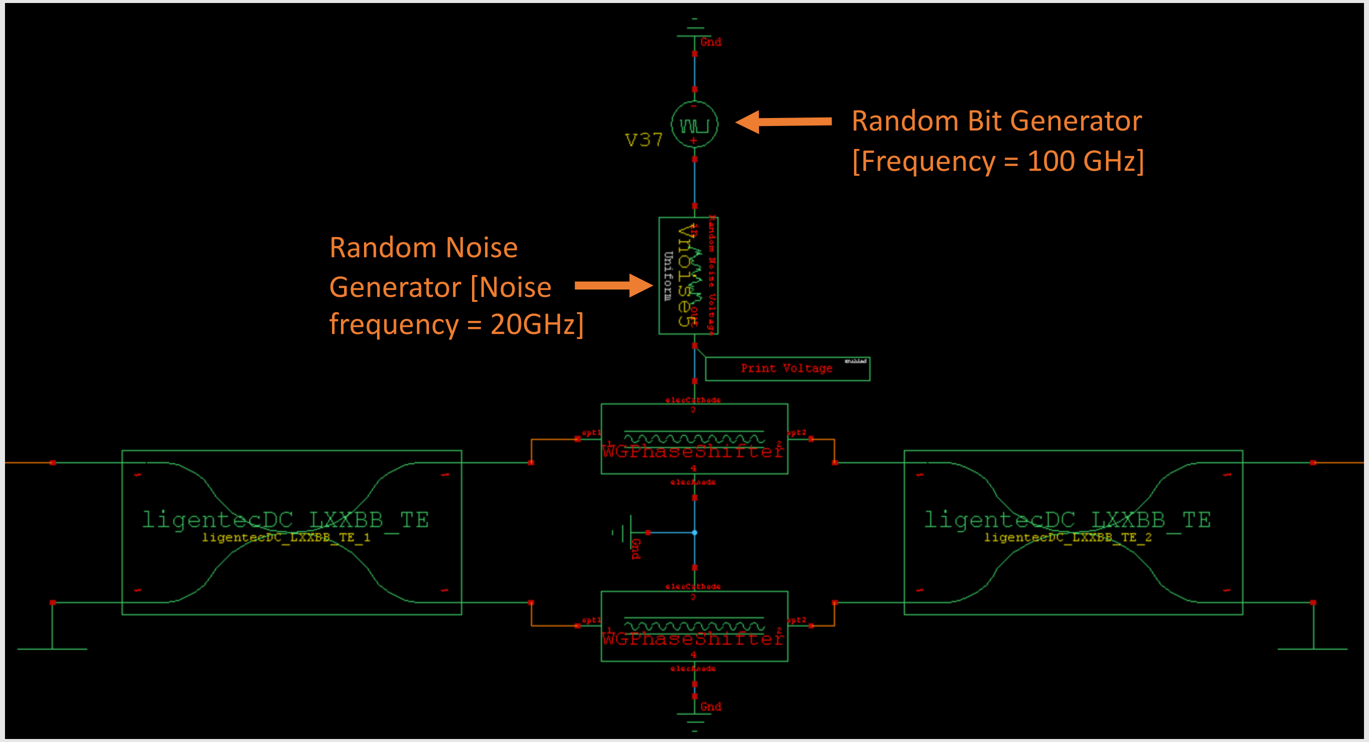


- ❑ Three port Laser [Library: OptiSPICE]:
  Port1 -> Optical
  Port2 -> Magnitude
  Port3 -> Phase
- ❑ Laser Frequencies: 190.8241 THz & 191.5291 THz

Overall electric field for MZM: $V(t) = VRF(t) + VDC$

The Transfer Function: $I_o = \left(\frac{T_r I_i}{2}\right)\left\{1 + cos\left[V(t)\left(\frac{\pi}{V_\pi}\right)\right]\right\}$ (ideal conditions)

Mach-Zehnder Modulator



Mach-Zehnder Modulator

- ❑ Directional Couplers: ligentecDC_LXXBB_TE [Library: Ligentec PDK]
- ❑ Waveguide Phase Shifters: neff. vs wavelength data imported for Ligentec straight WG *(shown in slide 5)* [Library: OptiSPICE]
- ❑ Arms length = 50um

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Transmitter Building Blocks

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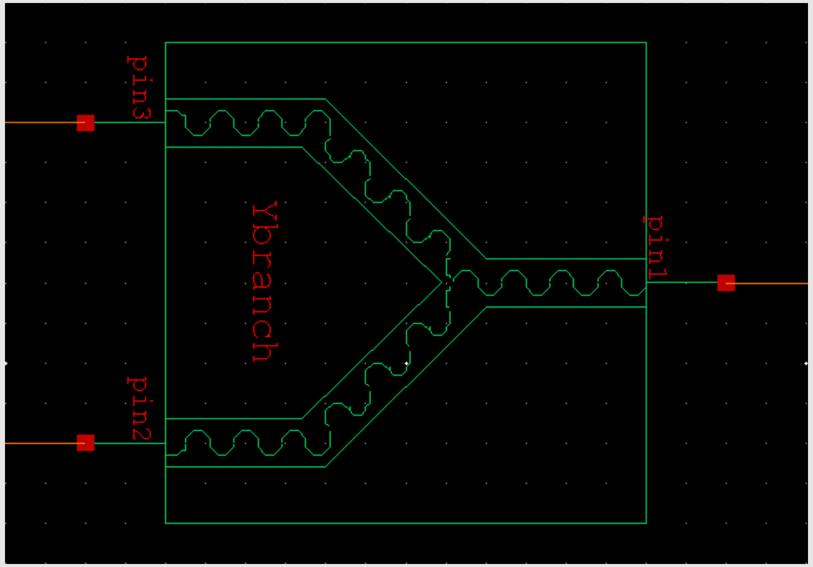
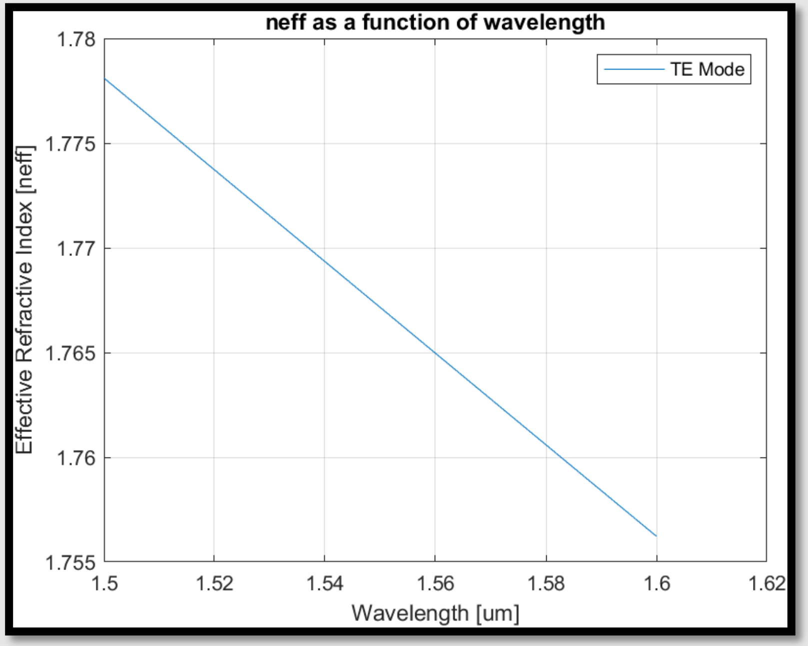
3dB Combiner



Y-branch [Library: OptiSPICE]
Used to combine two frequency channels

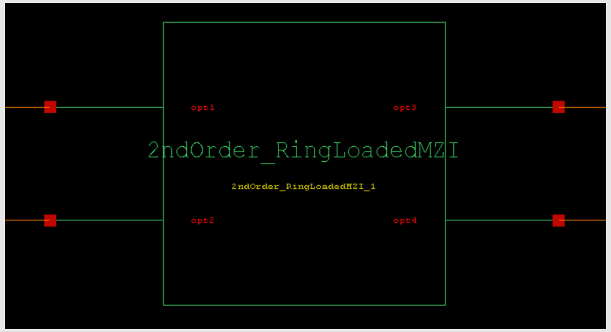
Ligentec Straight Waveguide

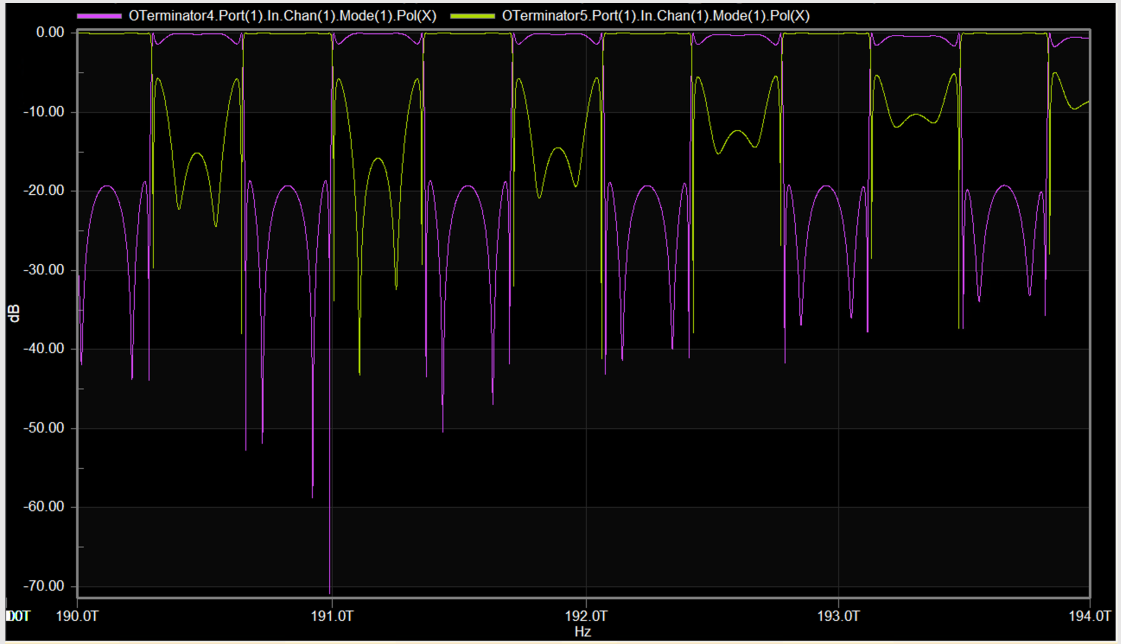
Straight waveguide between transmitter and receiver
Waveguide – ligentecStraight_TE [Library: Ligentec PDK]
Length = 500um
Modelled using data of neff as a function of wavelength



Receiver Building Blocks

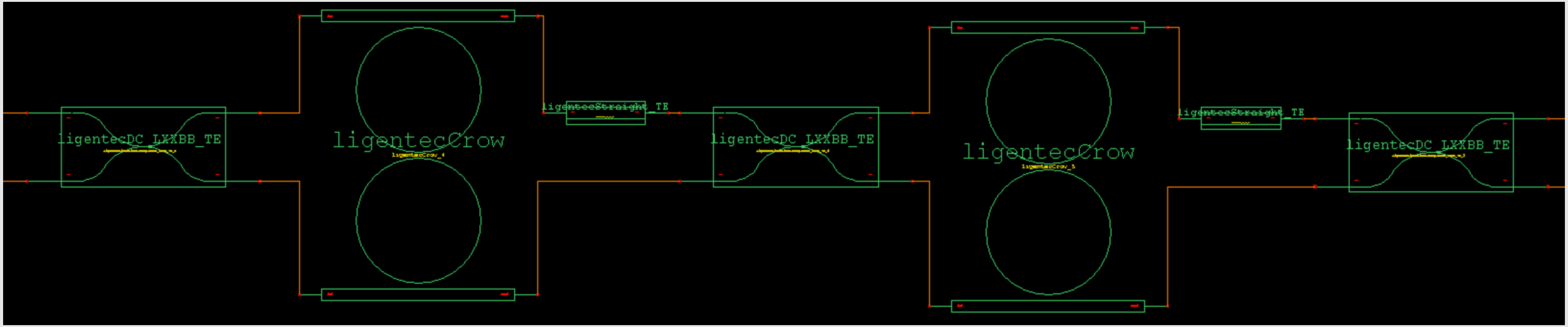
Optical Filter





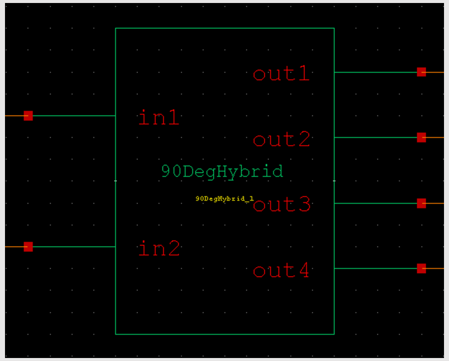
2nd Order Ring Loaded MZI

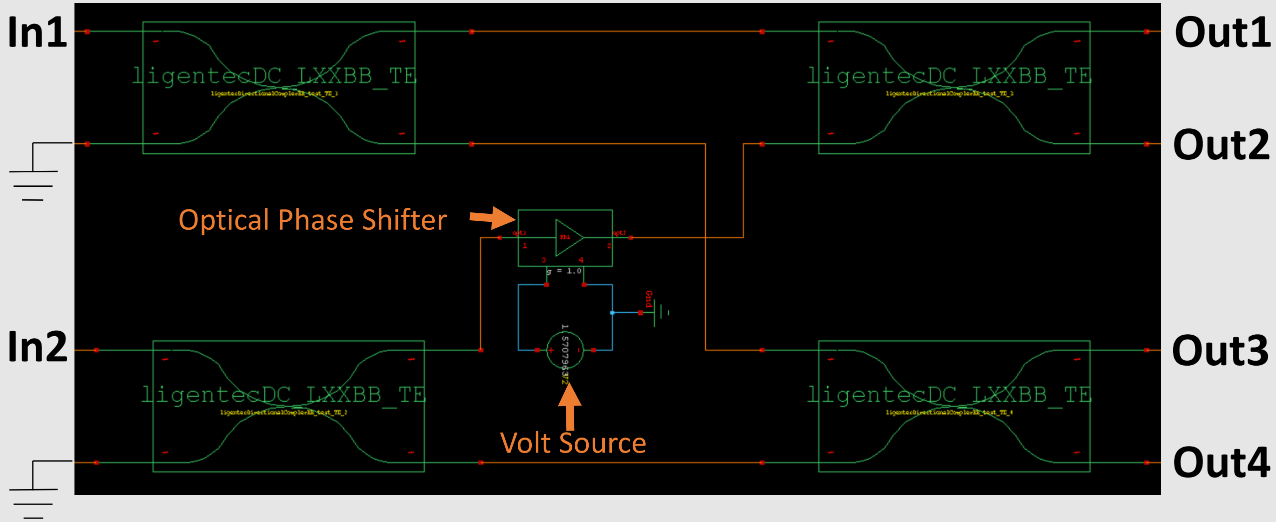
- Directional Coupler – ligentecDC_LX.XBB_TE [Library: Ligentec PDK]
- Waveguide – ligentecStraight_TE [Library: Ligentec PDK]
- 2nd order ring filter – ligentecCROW [Library: Ligentec PDK]
- Separate two channels
- Flat–top response
- Operational bandwidth range = 196.58 GHz
- FSR = 708.14 GHz



Receiver Building Blocks

90 Deg Hybrid





- ❑ The 90 Deg Hybrid mixes the incoming optical field with the local oscillator (LO) optical field and produces four outgoing signals with phase differences of 0, π, 3π/2 and π/2
- ❑ The real amplitudes of the PSK and LO signals are represented by $\overrightarrow{A_s}$ and $\overrightarrow{A_{LO}}$, respectively

PSK Signal ➡ $\overrightarrow{I_{n1}} = \overrightarrow{A_s}(t)e^{[-j(\omega_s(t)+\varphi s(t))]}$

Local Oscillator Signal ➡ $\overrightarrow{I_{n2}} = \overrightarrow{A_{LO}}e^{[-j(\omega_{LO}(t)+\varphi_{LO}(t))]}$

$$\overrightarrow{Out_1} = \overrightarrow{A_s}(t)e^{[-j(\omega_s(t)+\varphi_s(t))]} + \overrightarrow{A_{LO}}e^{[-j(\omega_{LO}(t)+\varphi_{LO}(t))]}$$

$$\overrightarrow{Out_2} = \overrightarrow{A_s}(t)e^{[-j(\omega_s(t)+\varphi_s(t))]+\frac{\pi}{2}} + \overrightarrow{A_{LO}}e^{[-j(\omega_{LO}(t)+\varphi_{LO}(t))]-\frac{\pi}{2}}$$

$$\overrightarrow{Out_3} = \overrightarrow{A_s}(t)e^{[-j(\omega_s(t)+\varphi_s(t))]+\frac{\pi}{2}} + \overrightarrow{A_{LO}}e^{[-j(\omega_{LO}(t)+\varphi_{LO}(t))]+\pi}$$

$$\overrightarrow{Out_4} = \overrightarrow{A_s}(t)e^{[-j(\omega_s(t)+\varphi_s(t))]+\pi} + \overrightarrow{A_{LO}}e^{[-j(\omega_{LO}(t)+\varphi_{LO}(t))]+\frac{\pi}{2}}$$

90 Degree Hybrid

- ❑ 3-dB Directional Couplers - ligentecDC_LXXBB_TE [Library: Ligentec PDK]
- ❑ Optical Phase Shifter – [Library: OptiSPICE]
- ❑ Volt Source – pi/2 volt
- ❑ In1 = BPSK Signal
- ❑ In2 = Local Oscillator Signal
- ❑ Out1 = 0 (phase change)
- ❑ Out2 = pi (phase change)
- ❑ Out3 = 3*pi/2 (phase change)
- ❑ Out4 = pi/2 (phase change)

Receiver Building Blocks

Coherent Detection with Balanced Detectors

- Since Photodiode has a square law detection characteristic and the photocurrent is proportional to the square of the input optical signal, that is:

$$i(t) = R|\overrightarrow{E_n}(t)|^2$$

where, R is responsivity of the photodiode, $\overrightarrow{E_n}$ is the optical signal coming out of each arm of 90 Deg. Hybrid

- The instantaneous power incident on each photodiode can be calculated as follows:-

$$P_t = \frac{1}{2} Out_n Out_n^*$$

- Therefore, the instantaneous power incident on each arm of balanced detector is:-

$$P_{t1} = \frac{1}{2}\{|A_s(t)|^2 + |A_{LO}|^2 + 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}} cos(\omega_{IF}t + \Delta\varphi(t)\}$$

$$P_{t2} = \frac{1}{2}\{|A_s(t)|^2 + |A_{LO}|^2 + 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}} cos(\omega_{IF}t + \Delta\varphi(t) + \pi)\} = \frac{1}{2}\{|A_s(t)|^2 + |A_{LO}|^2 - 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}} cos\left(\omega_{IF}t + \Delta\varphi(t)\right)\}$$

$$P_{t3} = \frac{1}{2}\left\{|A_s(t)|^2 + |A_{LO}|^2 + 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}} cos\left(\omega_{IF}t + \Delta\varphi(t) + \frac{3\pi}{2}\right)\right\} = \frac{1}{2}\{|A_s(t)|^2 + |A_{LO}|^2 + 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}} sin\left(\omega_{IF}t + \Delta\varphi(t)\right)\}$$

$$P_{t4} = \frac{1}{2}\left\{|A_s(t)|^2 + |A_{LO}|^2 + 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}} cos\left(\omega_{IF}t + \Delta\varphi(t) + \frac{\pi}{2}\right)\right\} = \frac{1}{2}\{\underbrace{|A_s(t)|^2 + |A_{LO}|^2}_{\text{Direct detection components of optical signal and LO}} \underbrace{- 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}} sin\left(\omega_{IF}t + \Delta\varphi(t)\right)}_{\text{Coherent detection term due to mixing between optical signal and LO}}\}$$

$$where, \omega_{IF} = \omega_s - \omega_{LO} \; and \; \Delta\varphi(t) = \varphi_s(t) - \varphi_{LO}$$

Direct detection components of optical signal and LO

Coherent detection term due to mixing between optical signal and LO

- Since $|A_s(t)^2 \ll |A_s(t).A_{LO}|$, the significant component is the last term.

Receiver Building Blocks

Homodyne Balanced Detection (Ideal)

$$\mathrm{I(t)} = \mathrm{Pt}_1 - \mathrm{Pt}_2 = 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}}cos\left(\omega_{IF}t + \Delta\varphi(t)\right)$$

$$\mathrm{Q(t)} = \mathrm{Pt}_3 - \mathrm{Pt}_4 = 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}}sin\left(\omega_{IF}t + \Delta\varphi(t)\right)$$

In ideal conditions, we assume the following:

- Responsivity of photodiode = 1
- $\omega_S = \omega_{LO}$ & $\varphi_{LO} = 0$
- The polarization state of the LO matches the incoming optical signal

$I(t) = 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}}cos\left(\varphi_s(t)\right)$ - The In-phase component

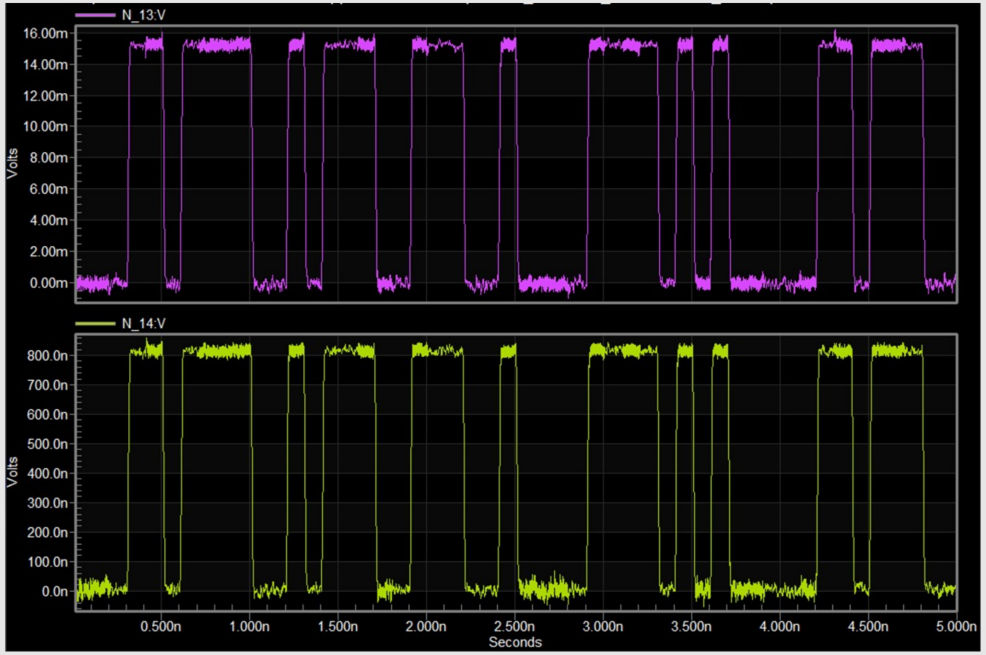
$Q(t) = 2.\overrightarrow{A_s}(t).\overrightarrow{A_{LO}}sin(\varphi s(t))$ - The Quadrature component

Channel1 Frequency = 190.8241 THz

LO1 Frequency = 190.8241 THz

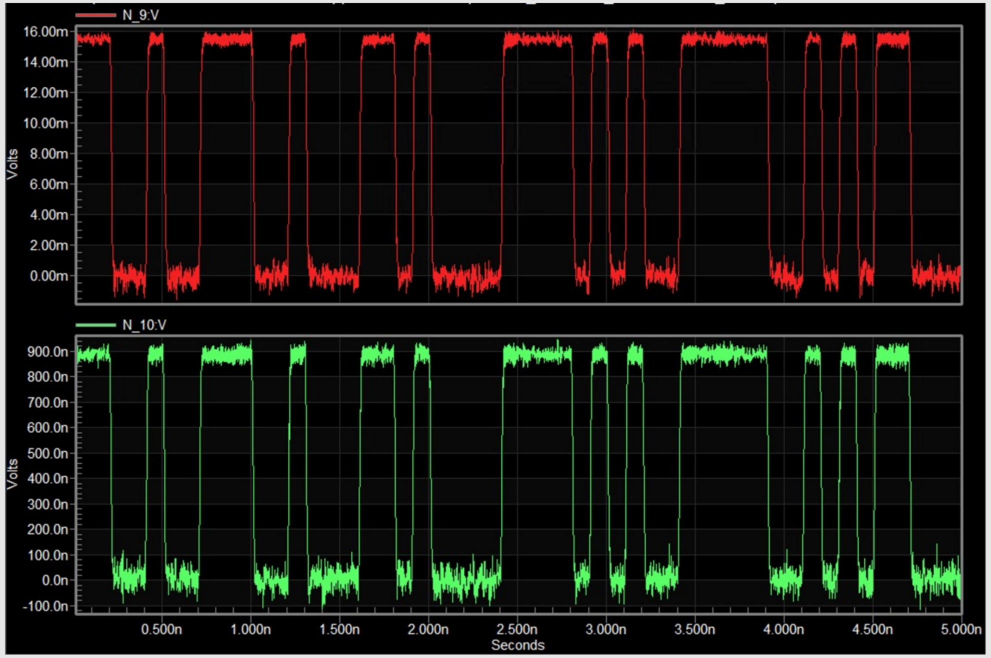
Channel2 Frequency = 191.5291 THz

LO2 Frequency = 191.5291 THz



Real part OR In-phase component of the detected BPSK signal **(Real(In1)),** measured from the upper branch of the balanced detector **I(t).**

Imaginary part OR Quadrature component of the detected BPSK signal **(Imag(In1)),** measured from the lower branch of the balanced detector **Q(t).** It's almost zero in ideal case.



Channel 1

Channel 2