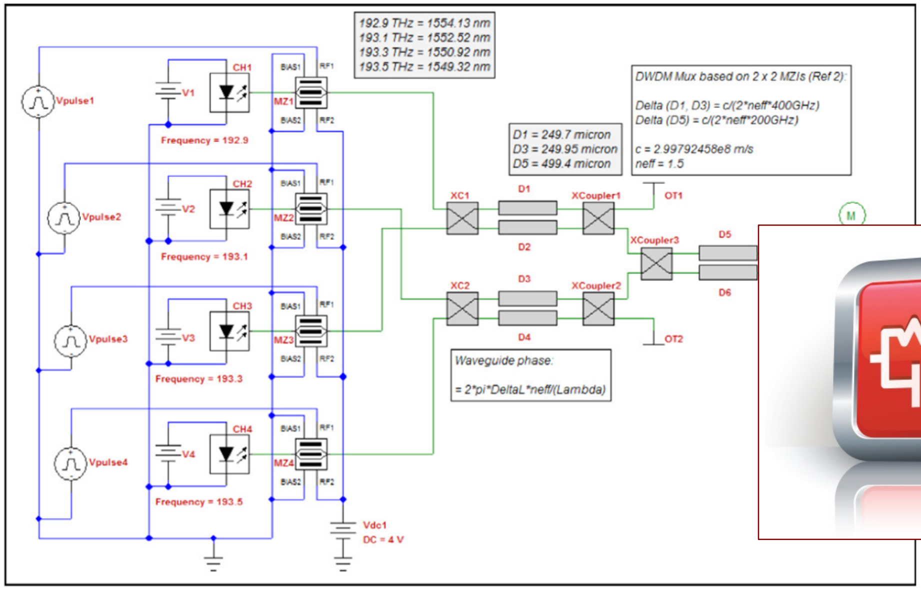
Optiwave
DESIGN SOFTWARE



OptiSPICE

Opto-Electronic Circuit Design
Software

Ring Resonator Gyroscope

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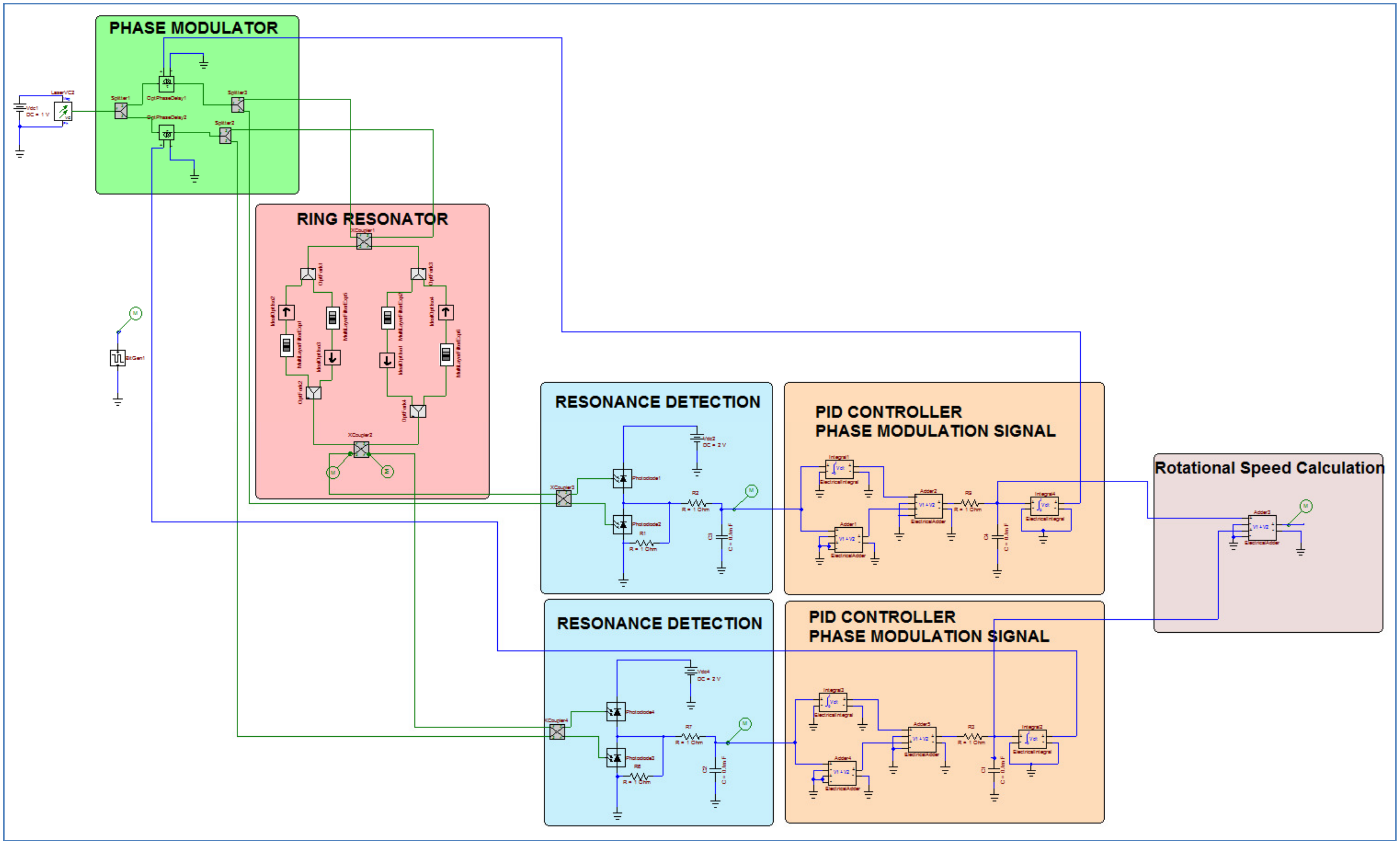
Fiber Optic Gyroscope Building Blocks

OptiSPICE
Opto-Electronic Circuit Design Software

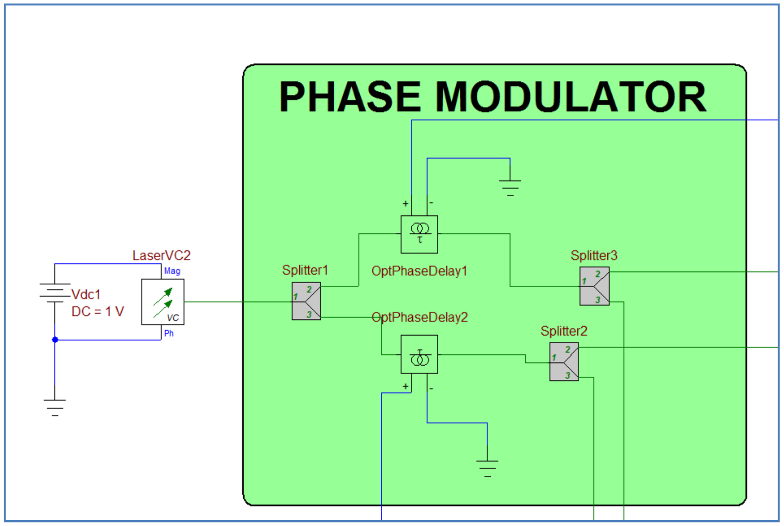


Optiwave

Phase Modulator

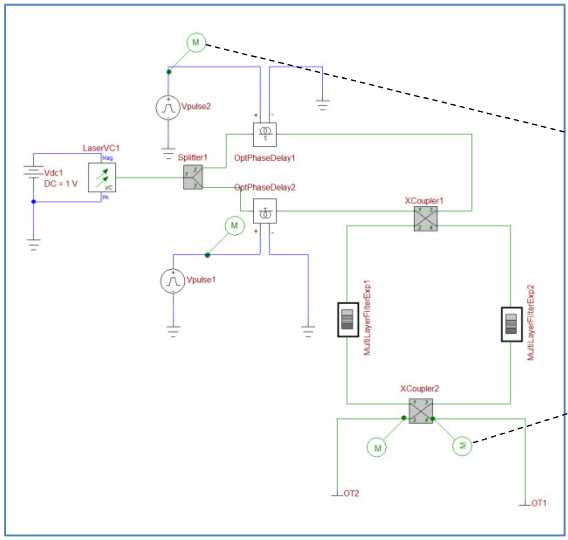
Phase Modulation

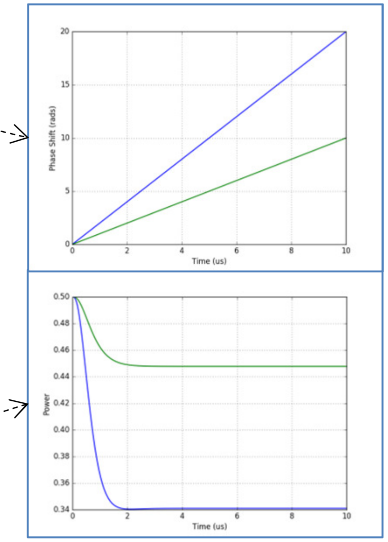
- The first splitter is used to create clockwise (CW) and counter clockwise (CCW) propagating waves in the ring resonator using a single laser source
- In OptiSPICE phase delay elements can be used to change the phase of an optical signal using a voltage node
- In this Ring Resonator Gyroscope design, phase delay elements are used to introduce a linear increase in phase over time to shift the carrier frequency of the CW and CCW propagating waves
- This frequency shift is used to keep the carrier frequency of the CW and CCW propagating waves at resonance



Linear Phase Increase

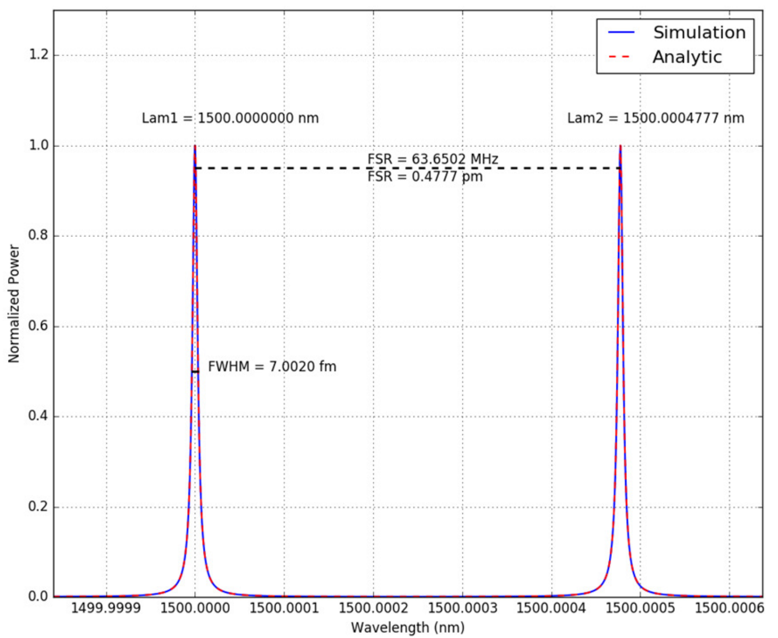
- The simulation results show the effect of the linear increase in phase
- At time=0 the carrier frequency is equal to the resonant frequency of the ring resonator
- The introduction of the linear increase in phase over time shifts the carrier frequency of the waves travelling inside the ring resonator
- Over time, because the carrier frequencies shift towards off-resonance, the output at the drop port decreases and reaches a new steady state





OptiSPICE Ring Resonator Model

- **Ring Resonator parameters**
  - Circumference of the ring, L = 3.14 m
  - Refractive index of the waveguide, n = 1.5
  - Propagation loss, a = 1
  - Coupling coefficients, r1 = 0.045, r2 = 0.045
  - Change in length (L1 = L + alphaL*V) , alphaL = 1
- **Basic Equations***
  - $m\lambda = nLR$, m = 1,2 3 ...
  - $\lambda_1 = 1550.000000000000\ nm$
  - $\lambda_2 = 1500.000477707159\ nm$
  - $FSR = \frac{c}{nL} = \frac{299792458}{(1.5)\ (3.14)} = 63.6502\ MHz$
  - $FWHM = \frac{(1 - r_1 r_2 a)\lambda^2}{\pi n L \sqrt{r_1 r_2 a}} = \frac{(1 - (0.0045)(0.0045)(1))(1550\ 10^{-9})^2}{\pi(1.5)(3.14)\sqrt{(0.0045)(0.0045)(1)}} = 7.0020\ fm$
  - $\beta = \frac{2\pi n}{\lambda}$
  - $\phi = \beta L = \frac{2\pi n}{\lambda} L$
  - $T_p = \frac{I_{pass}}{I_{input}} = \frac{r_2^2 a^2 - 2r_1 r_2 a cos(\phi) + r_1^2}{1 - 2r_1 r_2 a cos(\phi) + (r_1 r_2 a)^2}$
  - $T_d = \frac{I_{pass}}{I_{input}} = \frac{(1 - r_1^2)(1 - r_2^2)a}{1 - 2r_1 r_2 a cos(\phi) + (r_1 r_2 a)^2}$

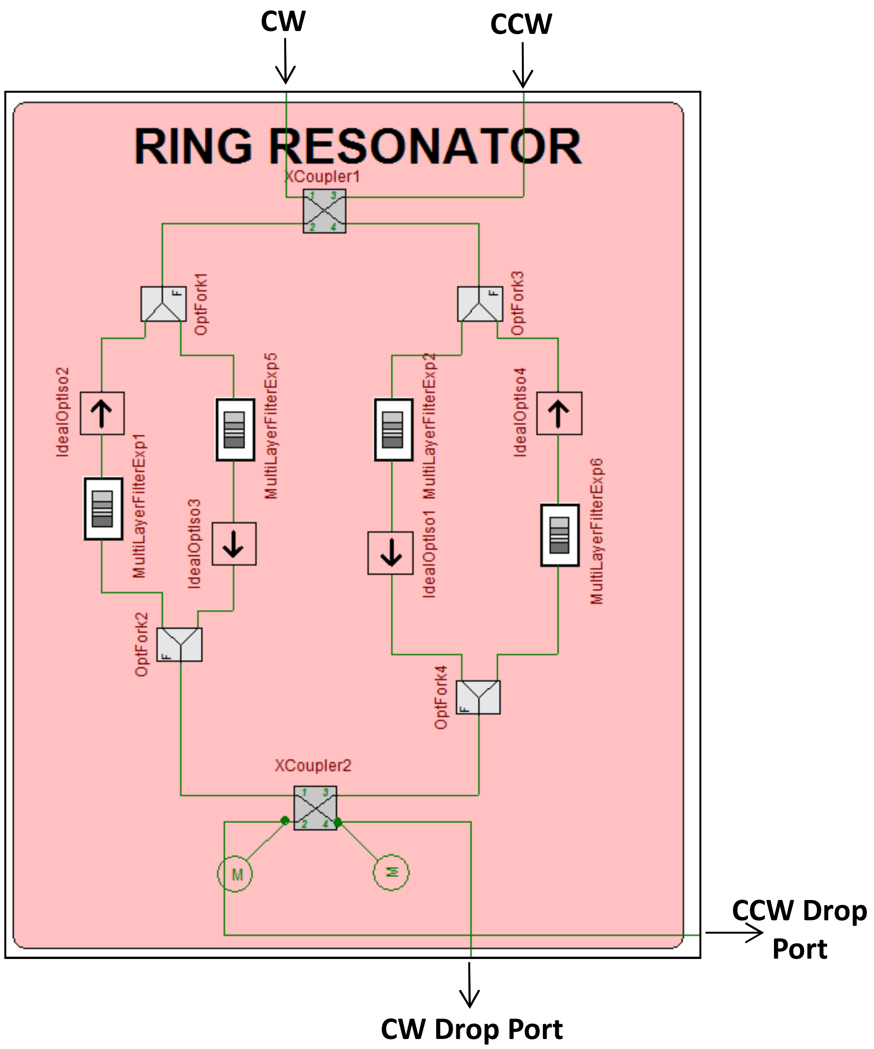


*Bogaerts, Wim, et al. "Silicon microring resonators." *Laser & Photonics Reviews* 6.1 (2012): 47-73.

Ring Resonator/Sagnac Effect

OptiSPICE Opto-Electronic Circuit Design Software

- **Building blocks**
  - 2 Cross Couplers
  - 4 Waveguides
  - 4 Optical Isolators
  - 4 Waveguides
- **OptiSPICE Model**
  - Explicit multilayer filter model is set up with a single layer
  - The length change in the waveguide can be controlled by a voltage source
  - The relationship between the length change in the waveguide and the voltage can be made linear or non-linear
  - Optical Forks and Isolators are used to separate clockwise (CW) and counter clockwise (CCW) traveling signals so a different length change (due to Sagnac effect) can be applied to each signal
- **Sagnac Effect***
  - Number of turns, N
  - Speed of light, c
  - Speed of light in dielectric medium, $v = \dfrac{c}{n}$
  - Area of the ring resonator, A
  - Rotational Speed, Ω
  - The change in distance seen by CW and CCW signals,
    $$\Delta L = \frac{4AN}{v}\Omega$$
  - The relationship between rotational speed and change in resonant frequency is given by,
    $$\Omega = \frac{nL\lambda}{4NA}\Delta f$$



CW

CCW

CCW Drop Port

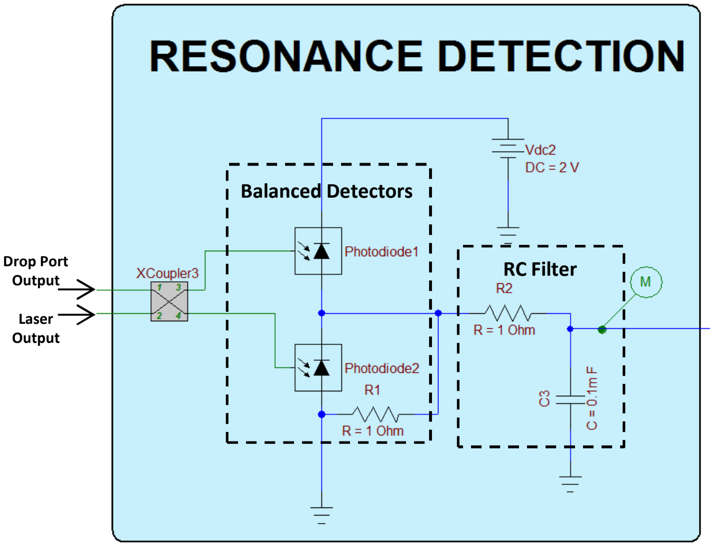
CW Drop Port

*VAWTER, GREGORY A., et al. *Developments in pursuit of a micro-optic gyroscope*. No. SAND2003-0665. Sandia National Labs., Albuquerque, NM (US); Sandia National Labs., Livermore, CA (US), 2003.

Resonance Detection

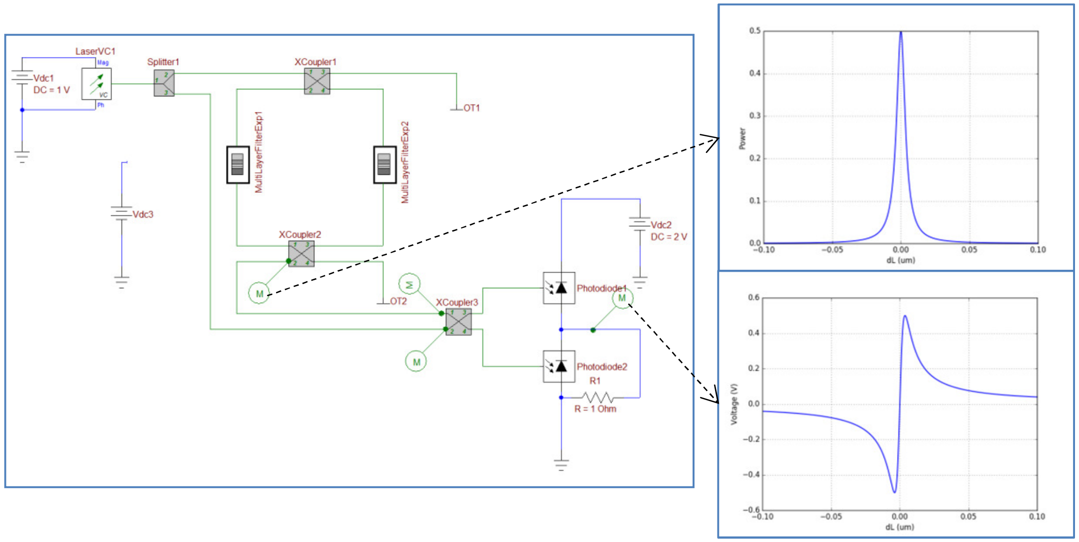
Keeping the carrier at resonant frequency

- 2 separate resonance detectors are used for CW and CCW propagating optical signals
- The output of the balanced detectors are used to drive the controller that generates the signal for phase modulation
- The RC filter following the output of the balanced detectors is used to filter out sudden changes at the output which may destabilize the circuit and cause divergence during simulation



Length vs. Detector Output

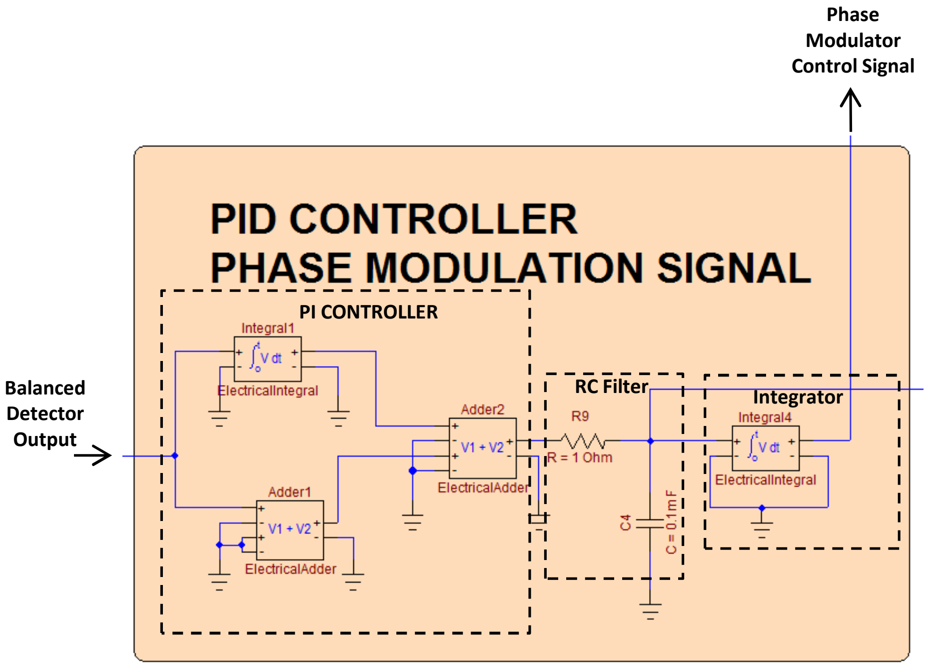
- The simulation results show the balanced detector output vs. the change in the circumference of the ring resonator
- The carrier frequency is equal to the resonant frequency of the ring resonator when dL = 0, the drop port output is at its peak and the balanced detectors are at 0 V
- The output of the balanced detectors increase/decrease as the circumference of the ring resonator increases/decreases
- The output at the drop port also decreases as the size of the circumference changes



PID CONTROLLER

Generating Phase Modulation Signal

- When there is a shift in resonant frequency the output of the balanced detectors shift away from 0 V
- The proportional-integral (PI) controller calculates a shift in frequency proportional the balanced detector output
- The integrator following the PI controller generates the phase modulator signal that shifts the carrier frequency going into the ring resonator
- The RC filter following the output of the PI controller is used to filter out sudden changes at the output which may destabilize the circuit and cause divergence during simulation



Simulation Results

Calculating the rotation speed

- In this example rotation speed of 3500 deg/h (0.01697 rad/s) was applied to the ring resonator by varying its circumference using the following equation,

$$\Delta L = \frac{4AN}{v}\Omega = \frac{4\pi(0.499745)^2 10}{299792458/1.5}(0.01697) = 1.1842\ nm$$

- The simulation results from OptiSPICE shows the output of the drop port moving back to resonance (max output) over time
- As the output of the drop port approaches resonance the balanced detector output reaches 0 due to the application of the linear phase increase by the phase modulator
- Finally the rotation speed can be calculated from the difference in resonant frequencies of CW and CCW signals using the following equation,

$$\Omega = \frac{nL\lambda}{4NA}\Delta f = \frac{(1.5)(3.14)(1550\ 10^{-9})}{4(10)(\pi)(0.49974^2)}(75.3772\ 10^3) = 3499.9995\ deg/h$$