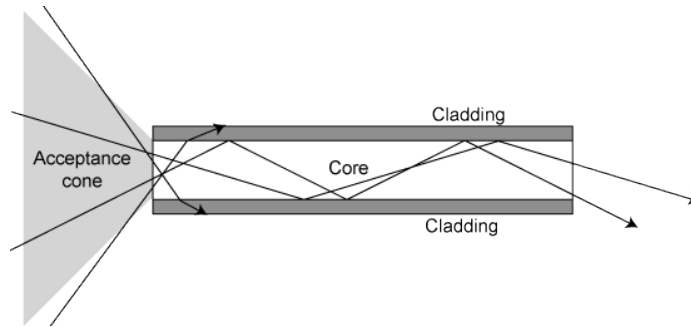
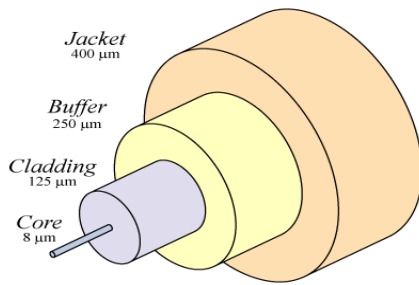


2x2 Fiber Coupler Components in Communication and Sensing

Basic structure



All-fiber Components

- o The necessary function of signal processing/ manipulation is performed whilst the signal is still guided by fiber
- o Components can be readily spliced to signal carrying circuit with a common fiber handling tool
- o Components realized from fiber in the form of fiber
- o No significant insertion loss due to geometry mismatch or mismatch in overlap of modal fields

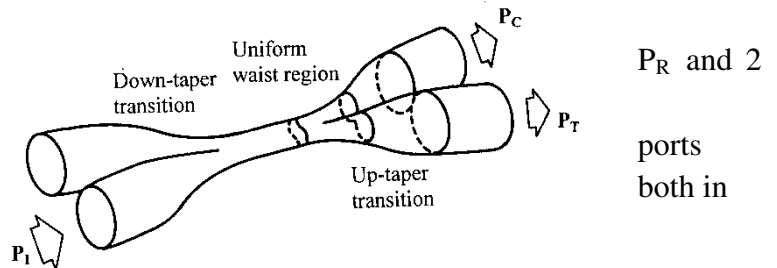
Major Devices

- o Fused Fiber Couplers: FFC
- o Fiber Amplifier: EDFA
- o Fiber Bragg Grating: FBG

Fused Fiber Coupler

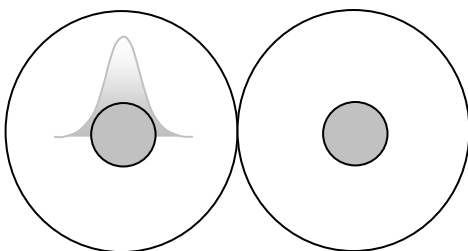
A 2x2 fused biconical tapered (FBT) coupler

- o A 4-port device: 2 input ports P_I & output ports P_T & P_C
- o Light injected into one of the input appears at either of the out ports or some ratio
- o Power splitting ratio depends on design parameters: operating wavelength and this is the key to realise many devices

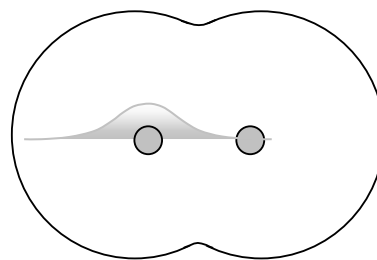


P_R and 2
ports
both in

Principle of Coupling: Overlap of modes



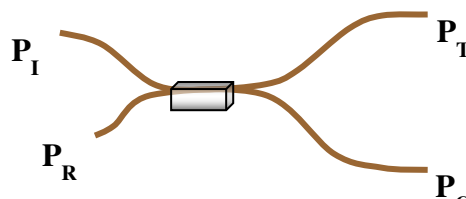
Optically isolated fiber-pair



Fused tapered waist

Coupling is due

- to cladding-mode coupling



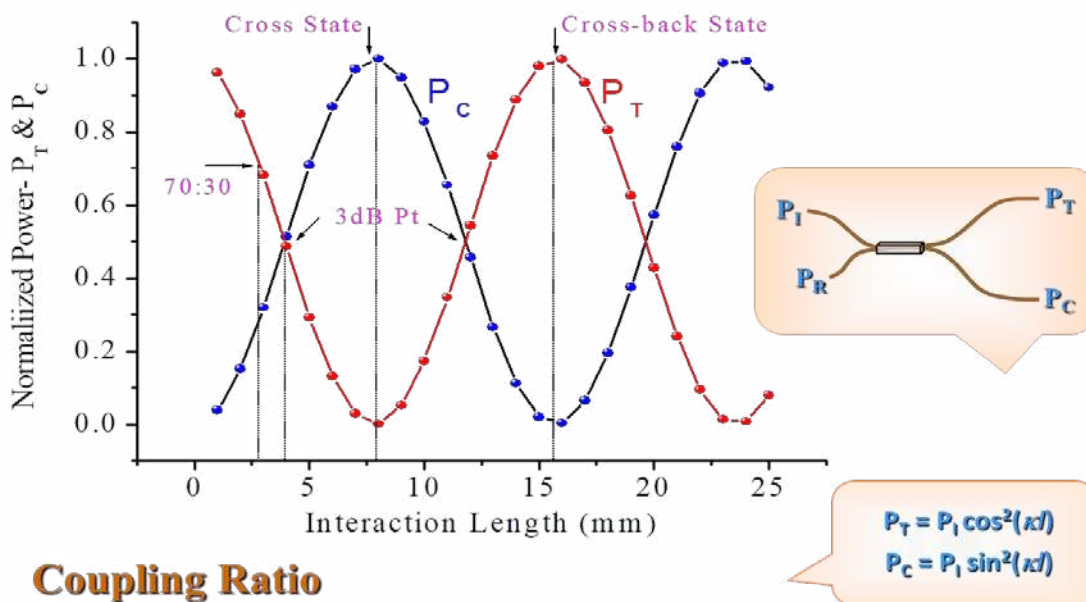
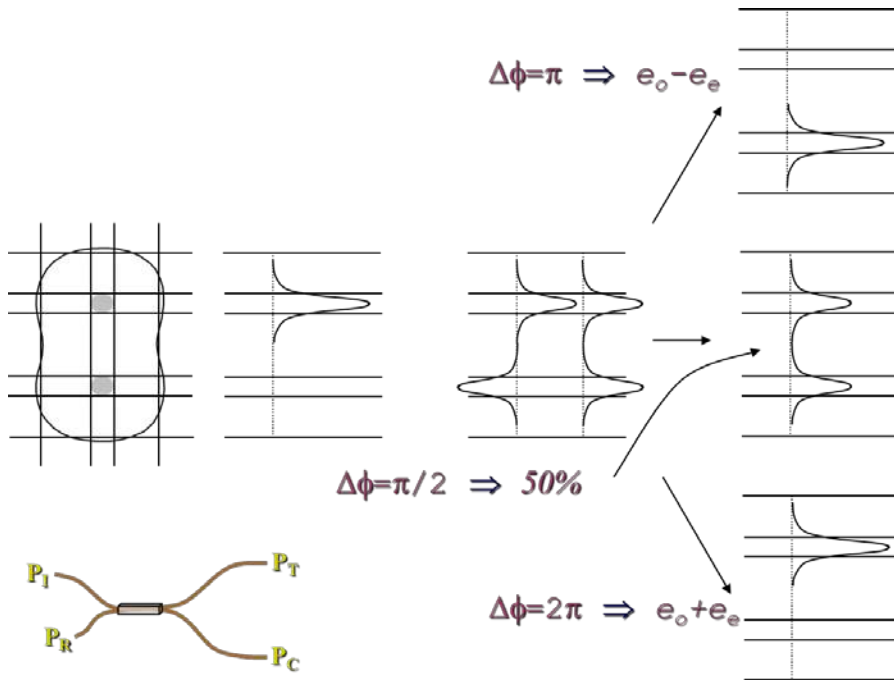
- to supermodes' beating

Power transfer

$$P_T = P_I \cos^2(\kappa l) \quad \kappa = \text{Coupling Coefficient}$$

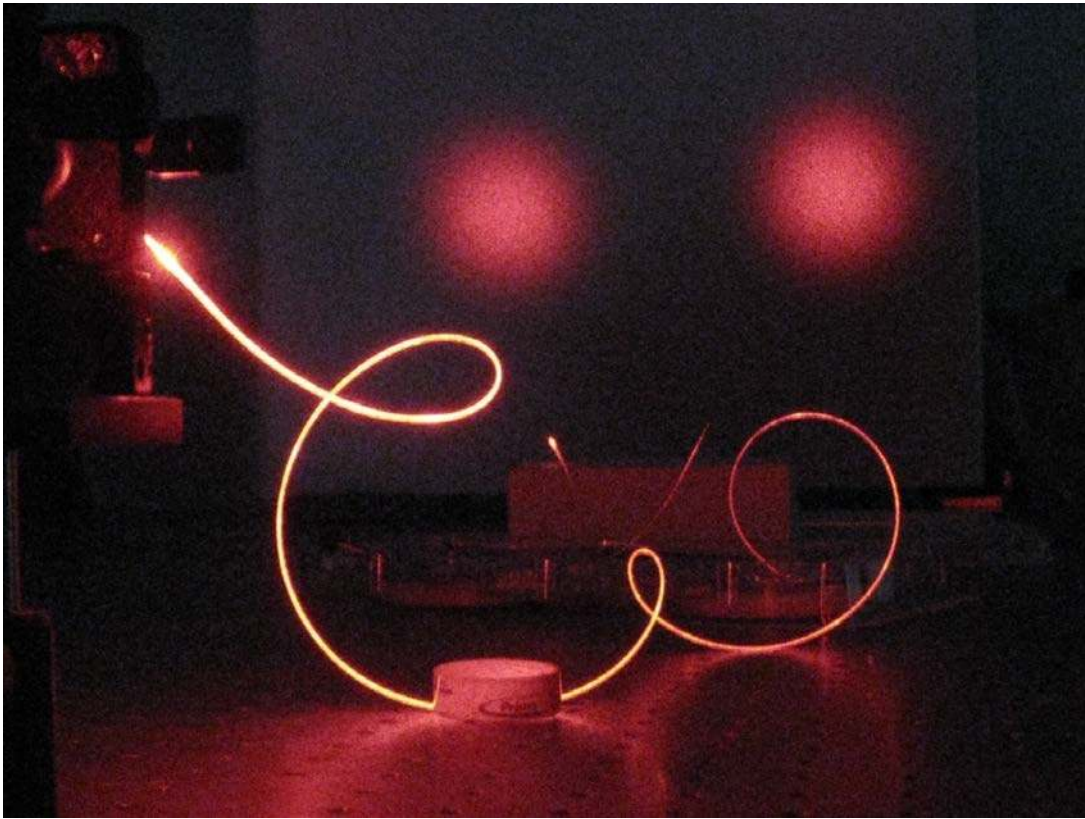
$$P_C = P_I \sin^2(\kappa l) \quad l = \text{Length of Interaction}$$

Coupling of Modes



Coupling Ratio

- depends on l at an operating wavelength λ
- varies with λ for a given coupler of length l



Measured Characteristics of Fabricated Splitters/ WDMs (Some Typical Results)

Characteristics of Power Splitters

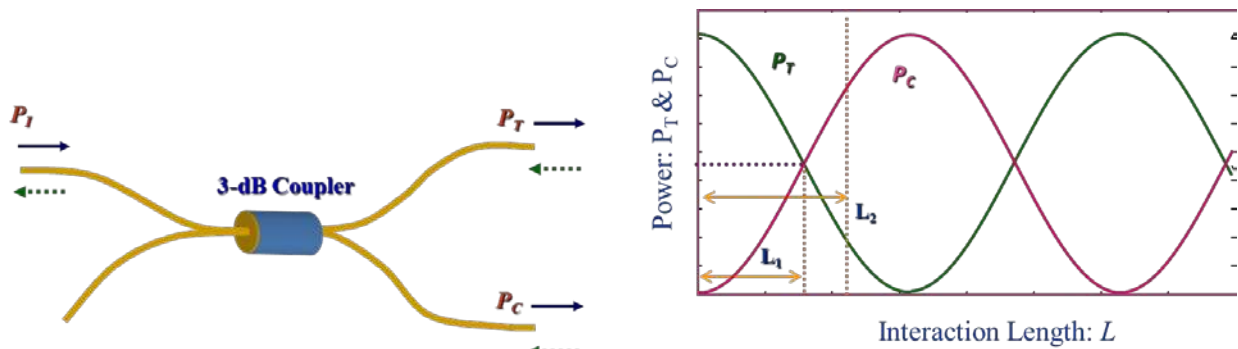
Characteristics	SMF @ 1310 nm	SMF @ 1550 nm	SMF @ 632.8 nm
Splitting Ratio	10% – 90%	10% – 90%	20% – 80%
Excess Loss	0.1dB – 0.3dB	0.1dB – 0.5dB	0.6dB – 1.1dB
Return Loss	40dB – 60dB	40dB – 60dB	50dB – 60dB

A typical WDM @ 1310/1550 nm

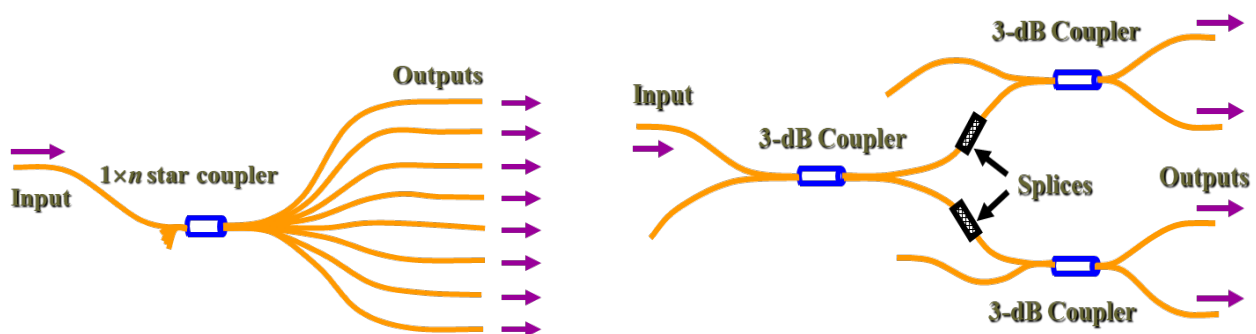
Characteristics	@ 1310 nm	@ 1550 nm
Wavelength Isolation	16.4dB	14.7dB
16dB Isolation Bandwidth	60nm	50nm
Excess Loss	0.61dB	0.37dB

- o Beam Splitter/Combiners
 - 3-dB Couplers
 - Tap/Access Couplers
 - Tree Couplers
- o Classical Wavelength Division Multiplexer/Demultiplexer (WDM/WDDM)
- o Wavelength Interleaver
- o Fiber Loop Mirror Reflector

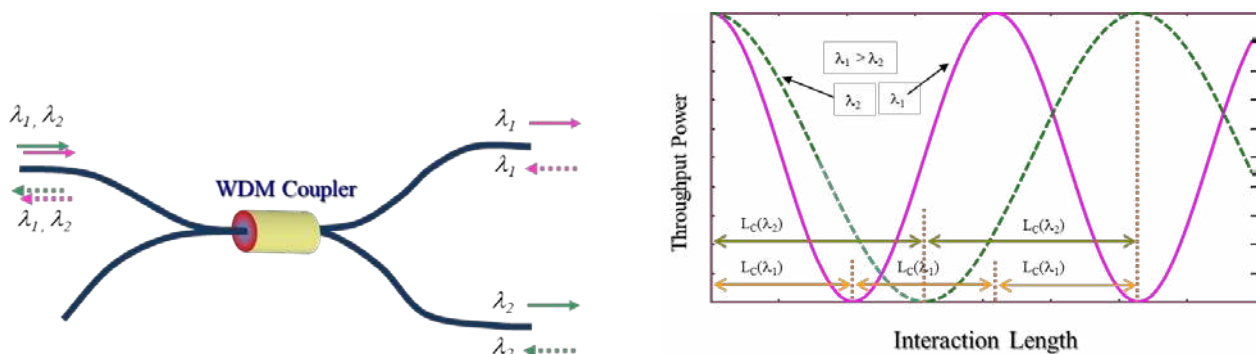
3-dB Couplers



Tree Coupler



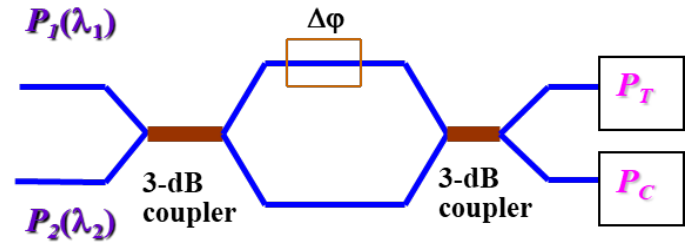
Classical WDM/WDDM



Wavelength Interleaver

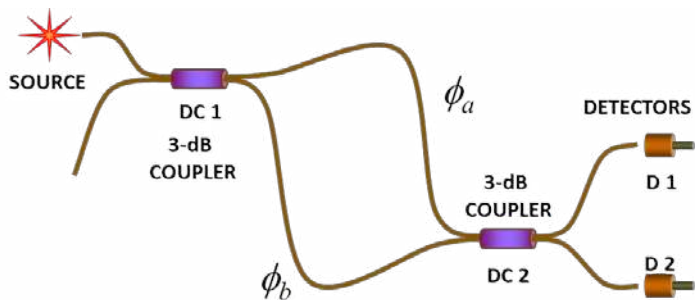
$$P_T = P_1(\lambda_1) \sin^2 \frac{\Delta\phi(\lambda_1)}{2} + P_2(\lambda_2) \cos^2 \frac{\Delta\phi(\lambda_2)}{2}$$

$$P_C = P_1(\lambda_1) \cos^2 \frac{\Delta\phi(\lambda_1)}{2} + P_2(\lambda_2) \sin^2 \frac{\Delta\phi(\lambda_2)}{2}$$



- o if $\Delta\phi(\lambda_1) = 2\pi$ & $\Delta\phi(\lambda_2) = \pi$, then $P_T = 0$ and $P_C = P_1(\lambda_1) + P_2(\lambda_2)$
i.e., power at both wavelengths now appear at the coupled port
- o $\Delta\phi$ satisfies the condition that $\Delta\phi(\lambda_1) - \Delta\phi(\lambda_2) = \pi$, both wavelengths can be combined into the coupled arm
- o in reverse direction thus it separates these wavelengths
- o in practice a flattop response needed; obtained by cascading MZs

Fiber MACH-ZEHNDER



a phase shift of $\pi/2$ across
DCs

$$E_1 = \frac{1}{2} E_0 [\exp(i\varphi_a) + \exp(i\varphi_b + \pi)]$$

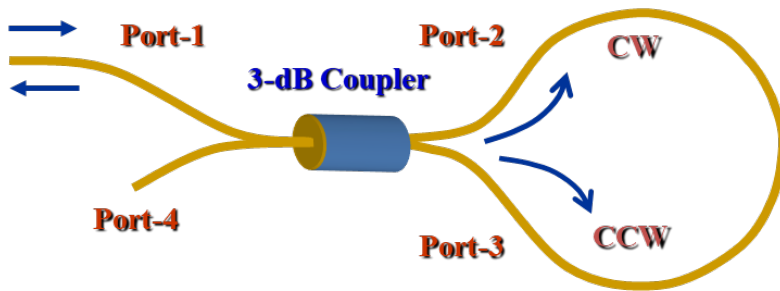
$$E_2 = \frac{1}{2} E_0 \left[\exp\left(i\varphi_a + \frac{\pi}{2}\right) + \exp\left(i\varphi_b + \frac{\pi}{2}\right) \right]$$

$$I \propto \langle E \cdot E^* \rangle$$

$$I_1 = \frac{1}{2} I_0 [1 - \cos(\varphi_a - \varphi_b)]$$

$$I_2 = \frac{1}{2} I_0 [1 + \cos(\varphi_a - \varphi_b)]$$

Fiber Loop Mirror



- o resonator cavity in fiber laser
- o passive fiber based FP devices
- o duplex transmission using single light source at one end
- o non-linear loop mirror, add-drop/switch

port-4:

$$E_4 = \underbrace{\frac{E_0}{\sqrt{2}} e^{i.0} \times e^{i\varphi} \times \frac{1}{\sqrt{2}} e^{i.0}}_{\text{CW}} + \underbrace{\frac{E_0}{\sqrt{2}} e^{i\pi/2} \times e^{i\varphi} \times \frac{1}{\sqrt{2}} e^{i\pi/2}}_{\text{CCW}}$$

$$E_1 = \underbrace{\frac{E_0}{\sqrt{2}} e^{i.0} \times e^{i\varphi} \times \frac{1}{\sqrt{2}} e^{i\pi/2}}_{\text{CW}} + \underbrace{\frac{E_0}{\sqrt{2}} e^{i\pi/2} \times e^{i\varphi} \times \frac{1}{\sqrt{2}} e^{i.0}}_{\text{CCW}}$$

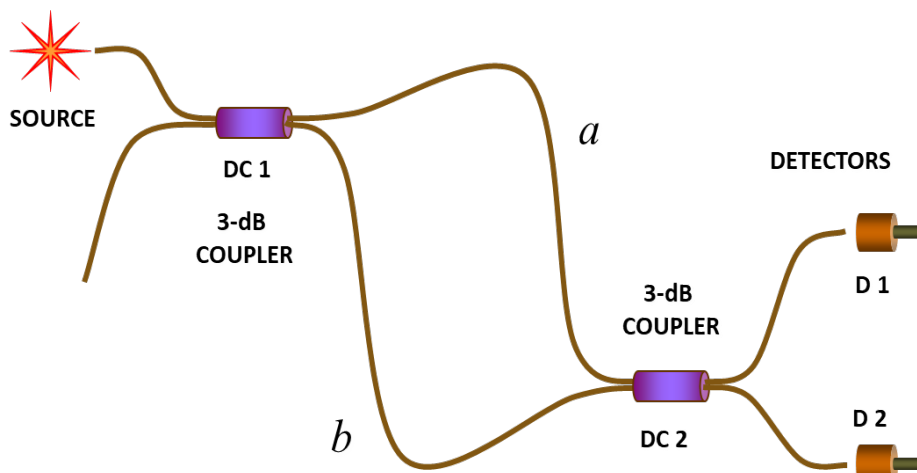
$$I \propto \langle E_4 \cdot E_4^* \rangle = 0$$

port-1:

$$I \propto \langle E_1 \cdot E_1^* \rangle = E_0^2 = I_0$$

INTERFERROMETERS

Two-beam Interferometer: Fiber MACH-ZEHNDER

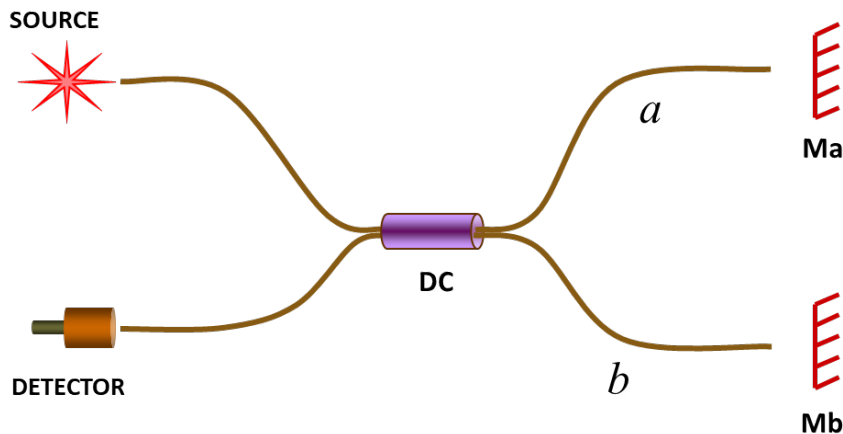


Transfer Function

$$I_1 = \frac{1}{2} I_0 [1 - \cos(\varphi_a - \varphi_b)]$$

$$I_2 = \frac{1}{2} I_0 [1 + \cos(\varphi_a - \varphi_b)]$$

Two-beam Interferometer: Fiber MICHELSON

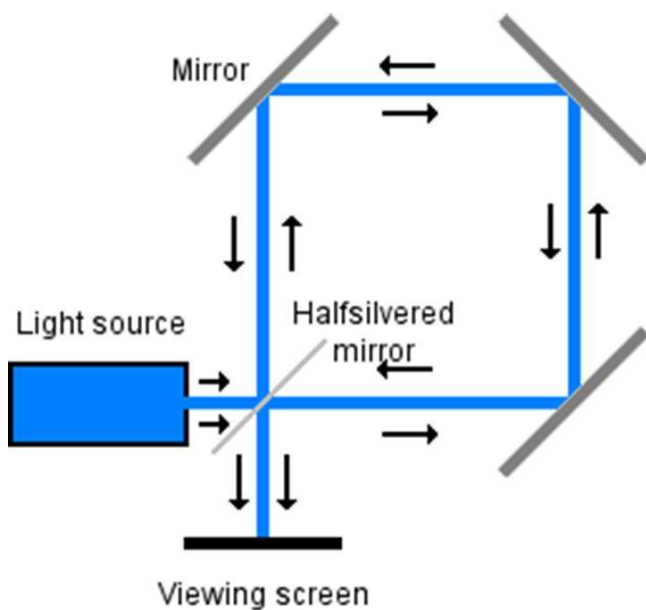


Transfer Function

$$I_1 = \frac{1}{2} I_0 [1 - \cos(\varphi_a - \varphi_b)]$$

$$I_2 = \frac{1}{2} I_0 [1 + \cos(\varphi_a - \varphi_b)]$$

Sagnac Interferometer



Assume Circular Cavity

$$\tau = 2\pi r/c$$

τ = propagation time

r = cavity radius

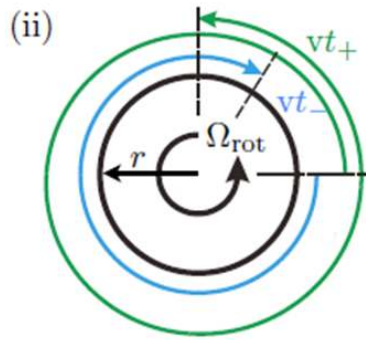
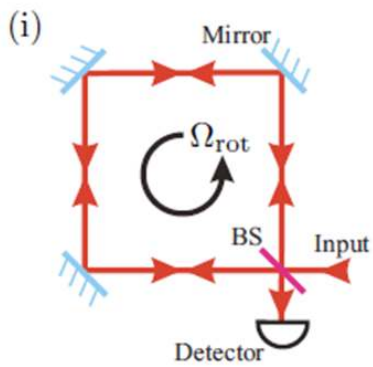
$$\Delta\tau = (2\pi + \Omega\tau)(r/c) - (2\pi - \Omega\tau)(r/c)$$

Ω = rotation per τ

$$\Delta\tau = 4\pi r^2 \Omega / c^2$$

$$\text{for } \omega, \Delta\phi = \omega \Delta\tau = 4\pi r^2 \omega \Omega / c^2$$

Fresnel-Fizeau Drag Effect



$$t_{\pm} = \frac{2\pi r \pm r \Omega_{\text{rot}} t_{\pm}}{v}$$

$$t_{\pm} \left(\frac{v \mp r \Omega_{\text{rot}}}{v} \right) = \frac{2\pi r}{v}$$

$$t_{\pm} = \frac{2\pi r}{v \mp r \Omega_{\text{rot}}}$$

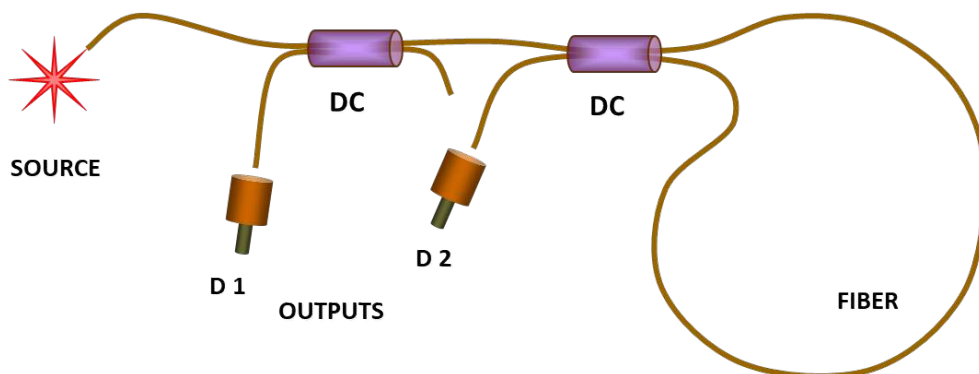
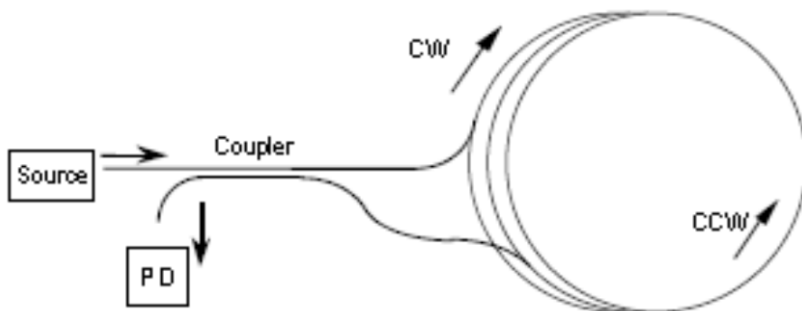
$$\delta t = t_+ - t_- ,$$

$$= \frac{2\pi r}{v - r \Omega_{\text{rot}}} - \frac{2\pi r}{v + r \Omega_{\text{rot}}}$$

$$\Rightarrow \delta t = \frac{4\pi r^2 \Omega_{\text{rot}}}{v^2 - (r \Omega_{\text{rot}})^2} .$$

$$\Delta\phi = \frac{4A \cdot \Omega_{\text{rot}}}{\lambda_0 v}$$

Closed Cavity Defined by Optical Fiber



loop rotated in its plane
with angular velocity Ω

phase shift between the two
counter propagating beams

$$\varphi_{\Omega} = 4\Omega\omega A/c^2$$