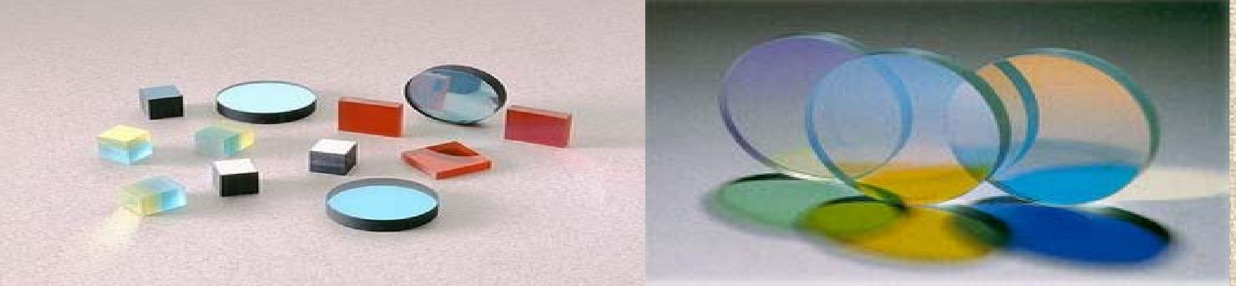
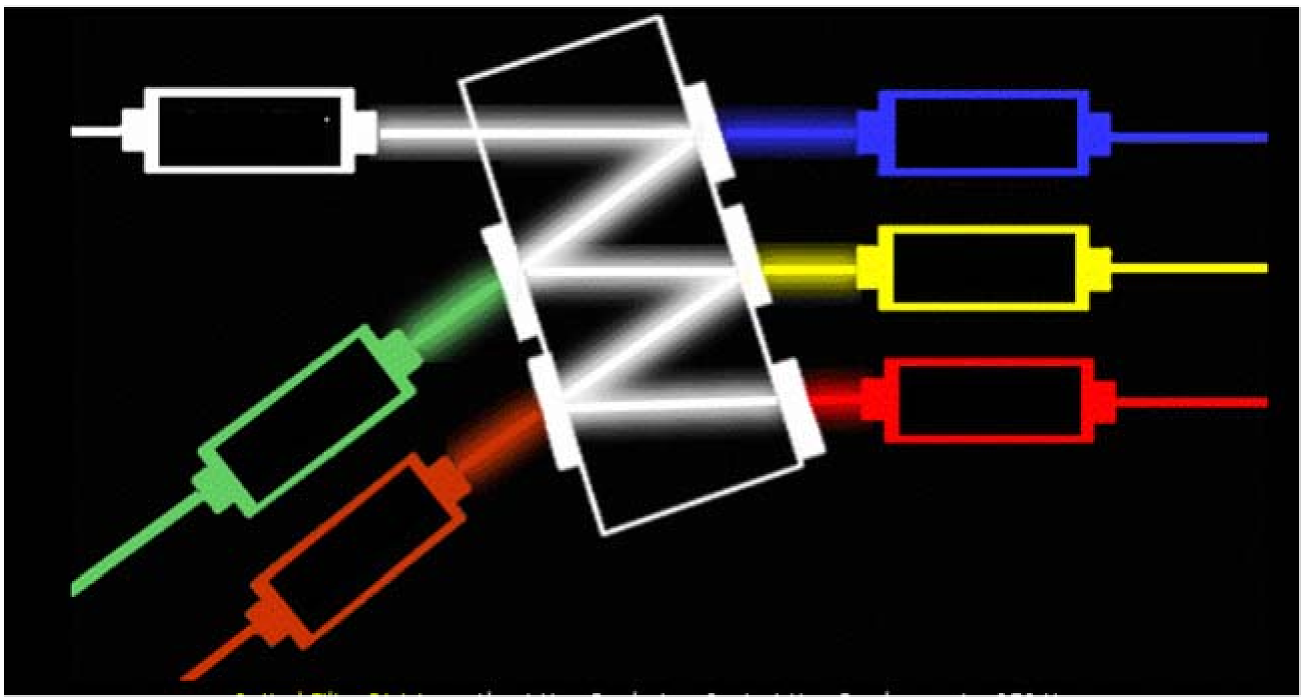
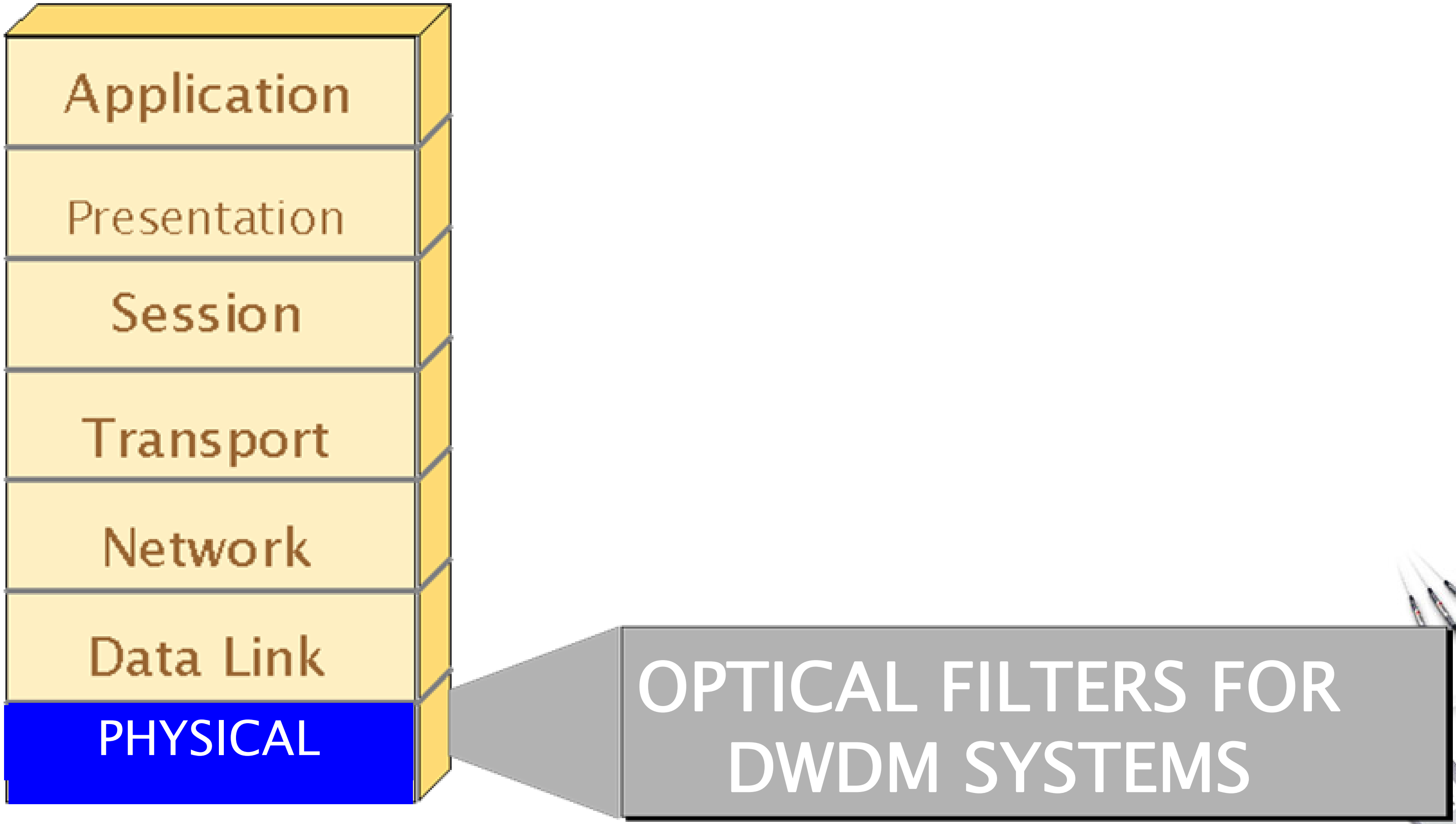


DWDM FILTERS; DESIGN AND IMPLEMENTATION

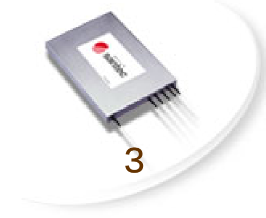


OSI REFERENCE MODEL



AGENDA POINTS

- NEED
- CHARACTERISTICS
- CLASSIFICATION
- TYPES
- PRINCIPLES
- BRAGG GRATINGS
- FABRY-PEROT ETALON
- DWDM APPLICATIONS



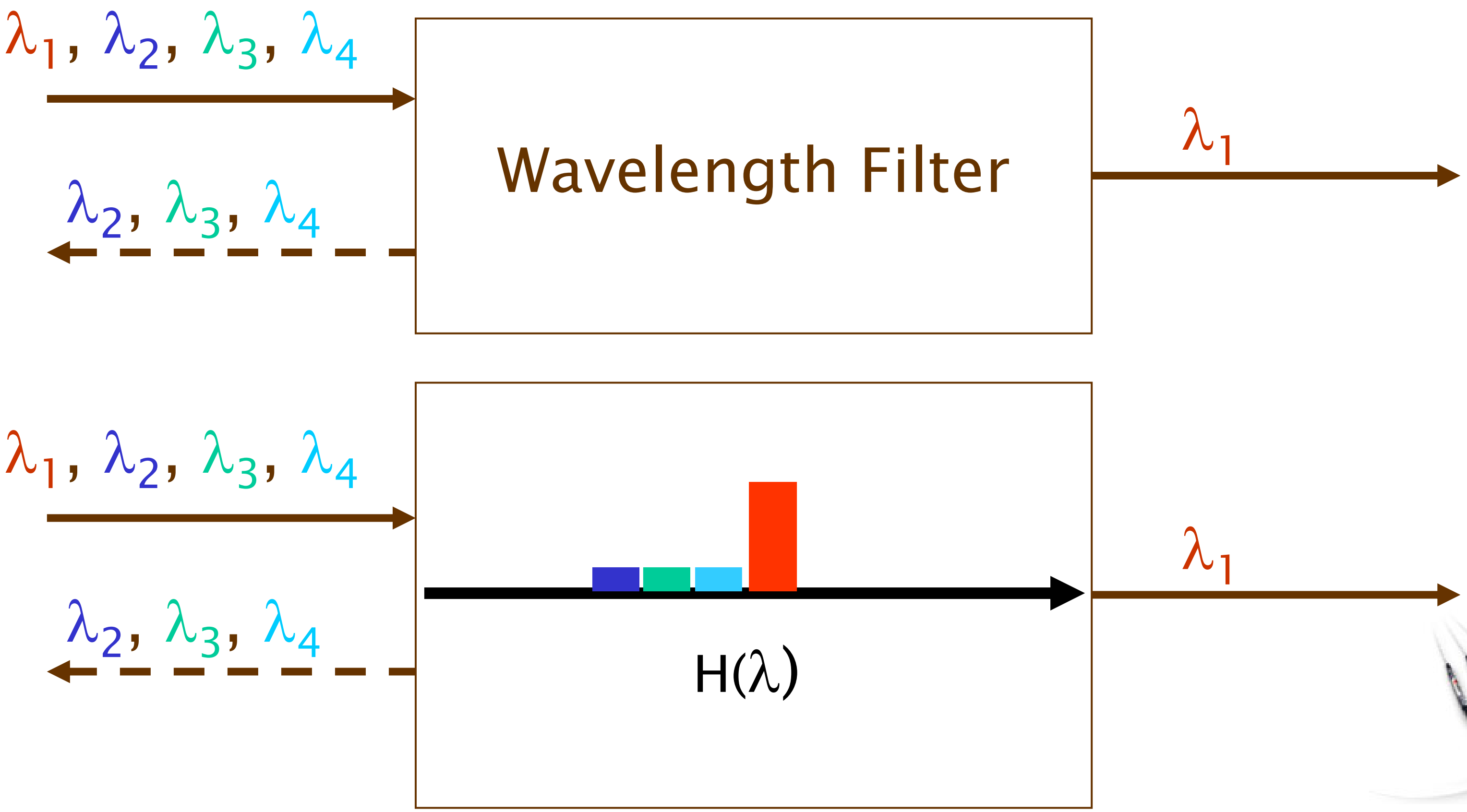
INTRODUCTION

DENSE WAVELENGTH DIVISION MULTIPLEXED (DWDM) SYSTEMS

- Only be feasible for communication if there exists a way to select channels for sending information specific to a given end-user
- Advantageous if such selection is done in the optical domain.

Avoids Electro-Optic and Opto-electric conversion

BLOCKING AND REFLECTING FILTERS



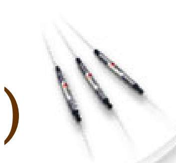
DESIRABLE CHARACTERISTICS OF OPTICAL FILTERS

- Wide Tuning Range →

  Enables Selection of a large number of Channels

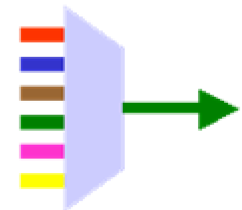
- Fast tuning
- Low insertion loss
- Polarization Insensitivity
- Stability with respect to environmental changes (T,P.H,N)
- Low aging effect
- Low cost manufacturability (cost effectiveness)
- Ease of Integration →

Allows easy splicing to other devices, e.g., coupler, amplifier



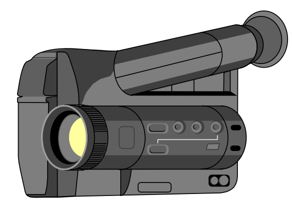
CLASSIFICATION OF OPTICAL FILTERS

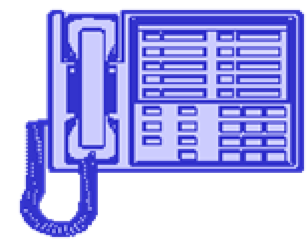
1. FIXED WAVELENGHT FILTERS



- Zero Response Time
- Typical application in Receiver Filters

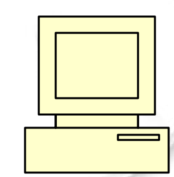
2. SLOW TUNABLE FILTERS





- Response times ~ms
- Useful for circuit switched networks, e.g., Voice Telephony

3. FAST TUNABLE FILTERS

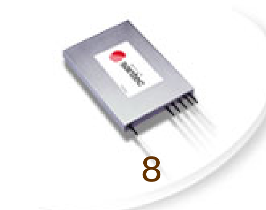


- Response times ~ns
- Useful for packet and cell switching, e.g., Computer Data Communication

-

TYPES OF OPTICAL FILTERS

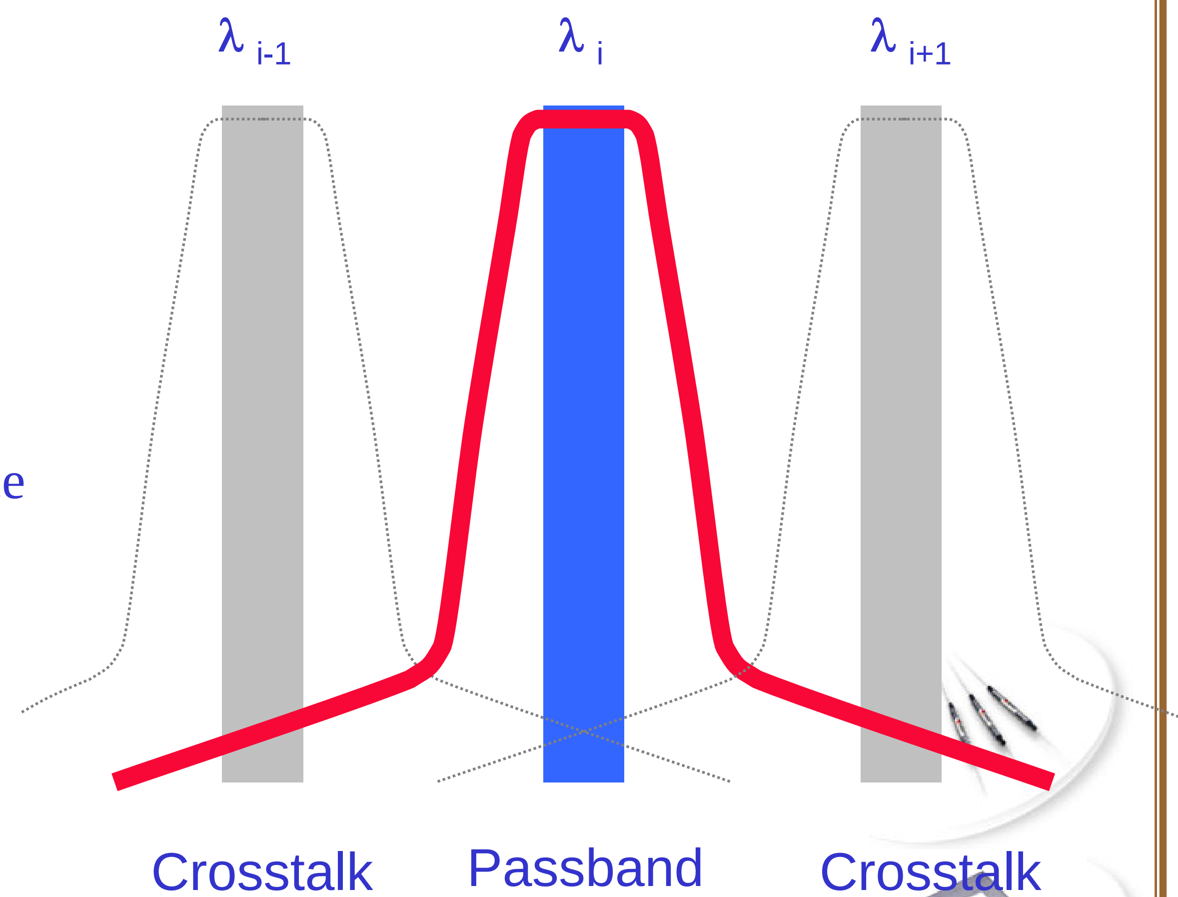
- The list below shows the range of filters that are available at present:
- Bandpass filters
  Calibration filters
  Cold mirrors
  Coloured glass filters
  Conversion filters
  Dichroic filters
  Heat absorbing filters
  Hot mirrors
  Hoya filters
  Infrared filters
  Interference filters
  IR Cut-off Filters
  Long pass filters
  Neutral density filters
  Photopic filters
  Schott filters
  Shortpass filters
  UV blocking filters
  UV filters



Optical Filters

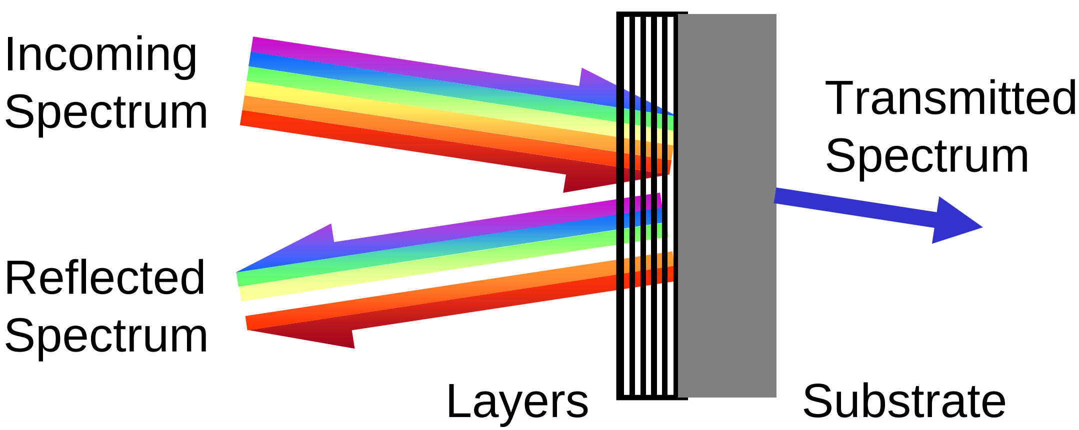
- **Passband**
  - Insertion loss
  - Ripple
  - Wavelengths (peak, center, edges)
  - Bandwidths (0.5 dB, 3 dB, ..)
  - Polarization dependence

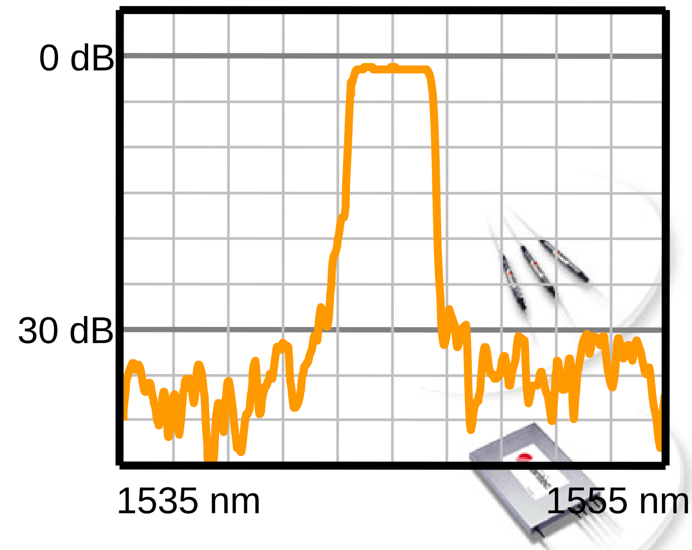
- **Stopband**
  - Crosstalk rejection
  - Bandwidths
  - (20 dB, 40 dB, ..)



Filters - Thin-film Cavities

- Alternating dielectric thin-film layers with different refractive index
- Multiple reflections cause constructive & destructive interference
- Variety of filter shapes and bandwidths (0.1 to 10 nm)
- Insertion loss 0.2 - 2 dB, stopband rejection 30 - 50 dB





MAJOR TYPES OF OPTICAL FILTERS

1. Fiber Grating Filters
2. Fabry Perot Filters
3. Multilayer Dielectric Thin-Film Filters
4. Mach-Zehnder Interferometers

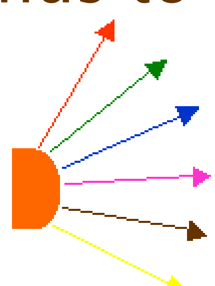
GOVERNING PRINCIPLES OF OPTICAL FILTERING

Interference Property

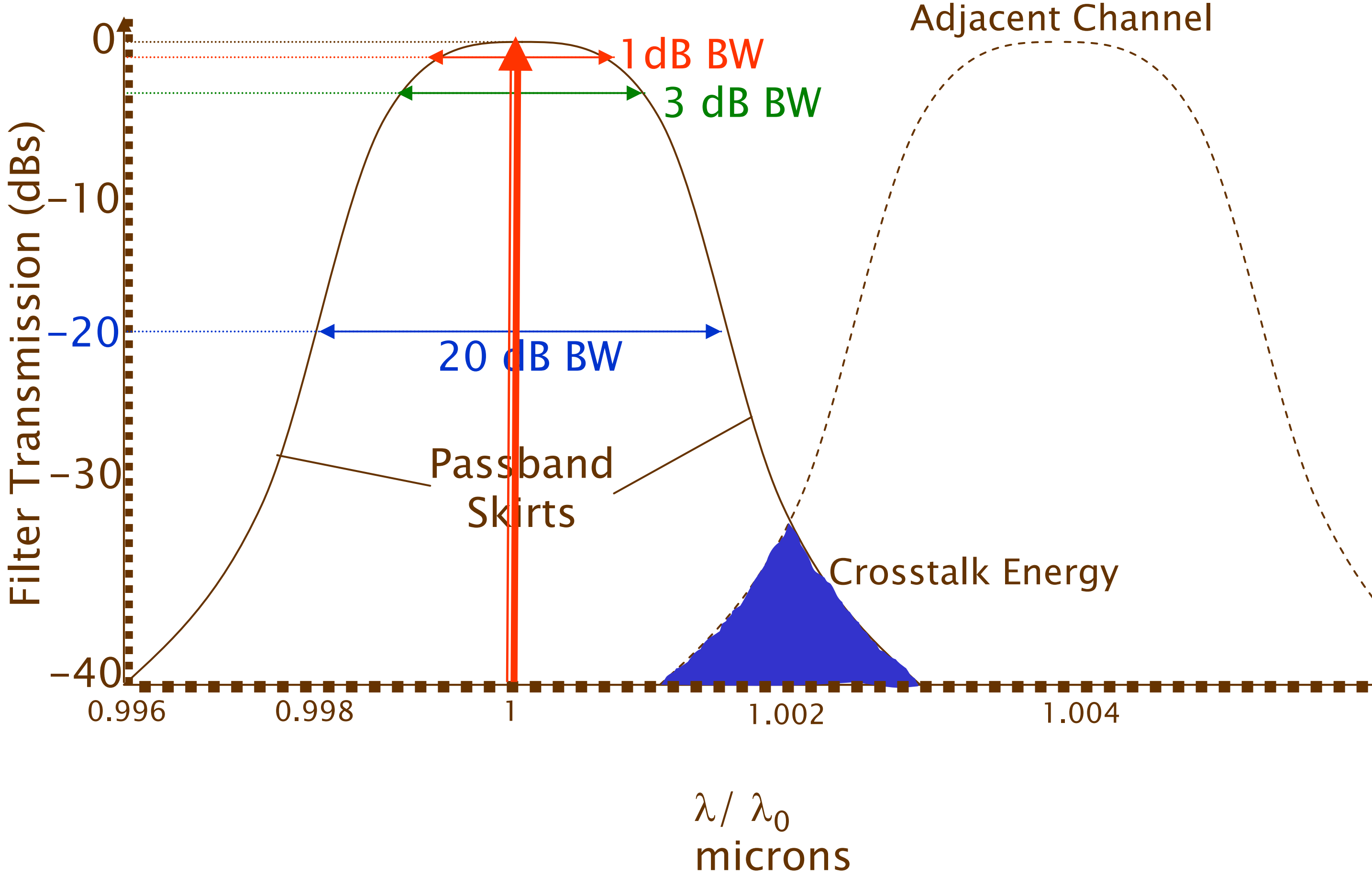
- Constructive —— Passband(s)
- Destructive —— Filtering out undesired wavelengths Stopband(s)

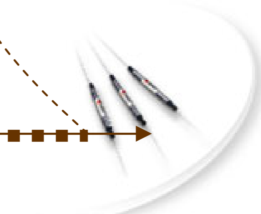
Diffraction Property

Light from a source tends to spread in all directions

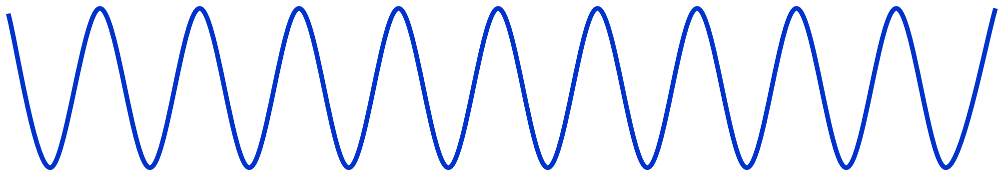


IMPORTANT SPECTRAL PARAMETERS





ELECTROMAGNETIC WAVE



- Representation: $A \times \cos(\omega t - \beta z)$

ω: Angular frequency

t: Time Scale

β: Propagation constant depending upon the medium;

$\beta = 2\pi n/\lambda$

z: Distance along the direction of propagation

- $\theta = (\omega t - \beta z)$ is the **PHASE SHIFT**. It can be achieved for the same wavelength if the two waves traverse paths of different lengths

GRATINGS

Second most Important Invention after LASERs

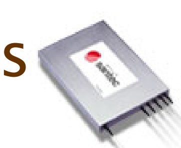
Contributing to All Optical Paragon

Grating is a device whose operation involves interference among multiple optical signals originating from the same source but with different relative *phase shifts*

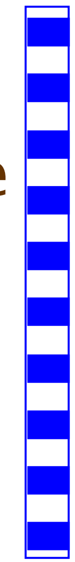
Gratings

↓

Separate light into its constituent wavelengths



GRATING PLANE

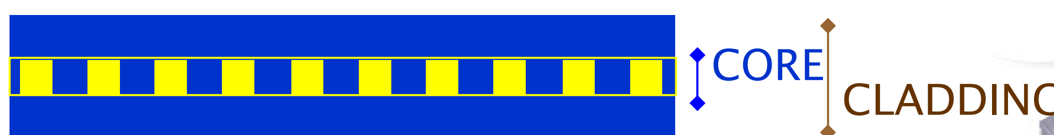


Multiple Narrow Slits placed equally apart on a plane

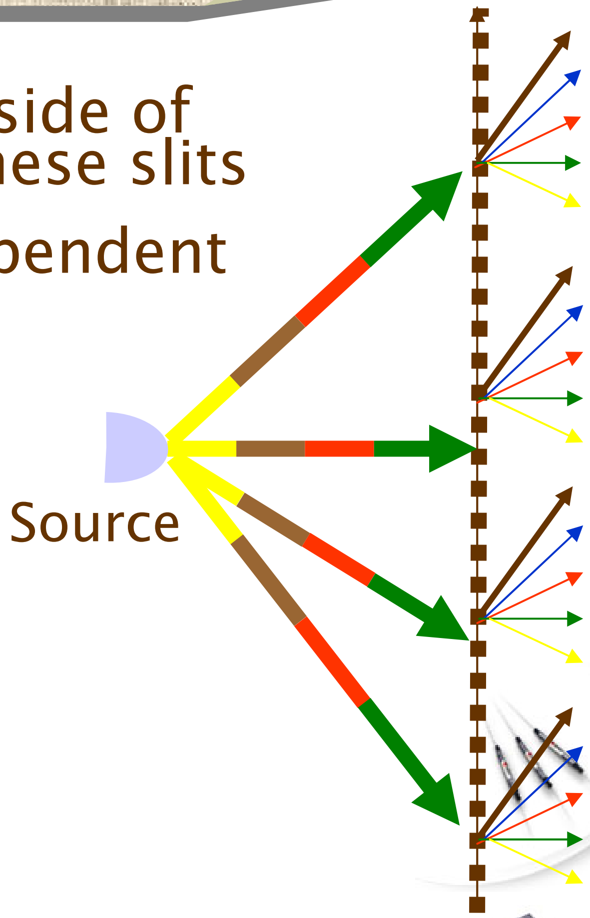
PITCH

The spacing between the slits ———— CRUCIAL

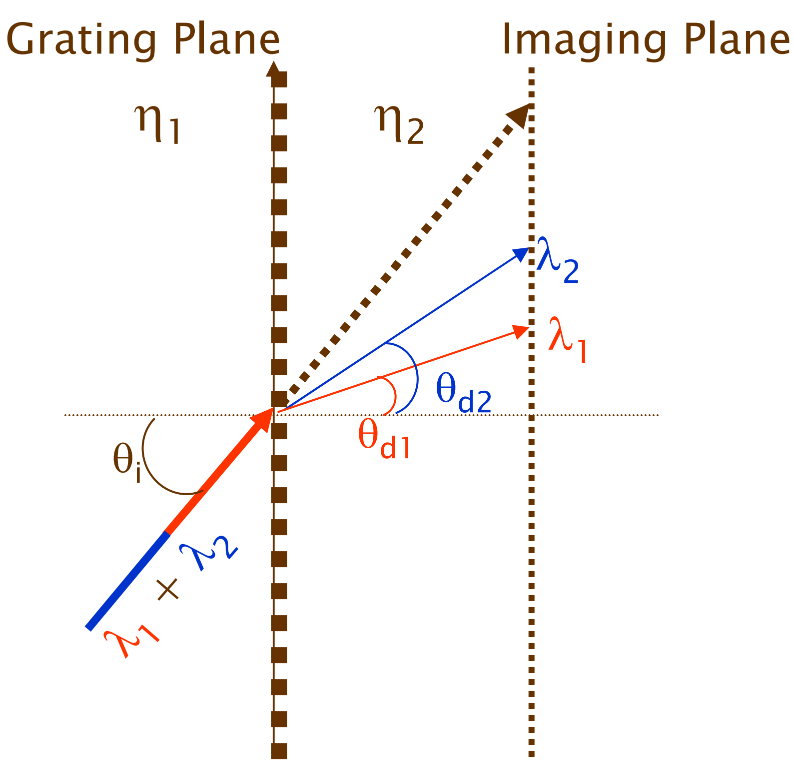
Gratings in OFC etched as periodic perturbations in the refractive index of the core



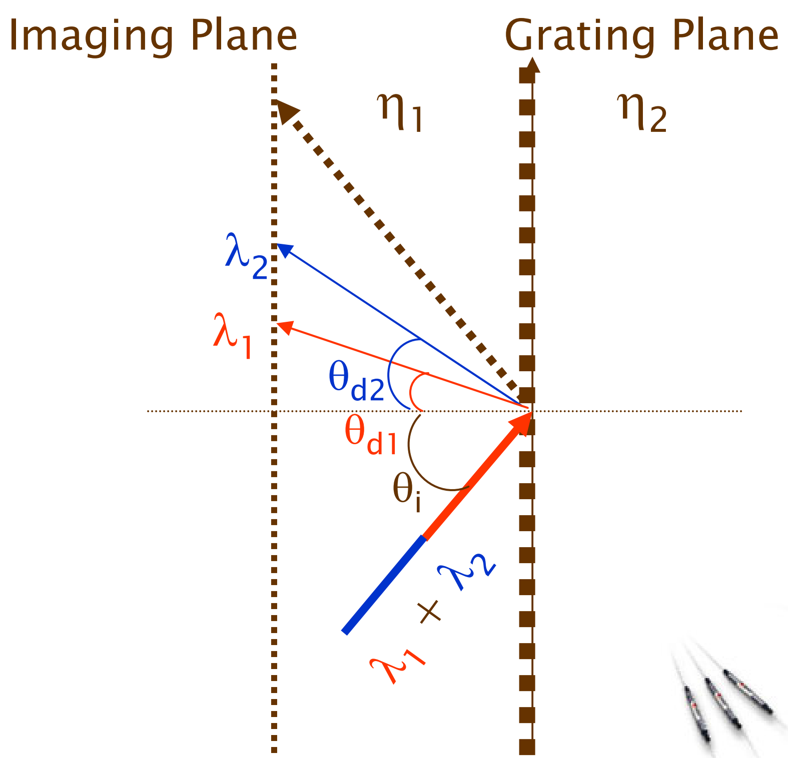
- Light incident from a source on one side of the gratings is transmitted through these slits
- Each narrow slit acts now as an independent source
- Diffraction tends to spread light in all directions



OPERATION



Transmission Grating



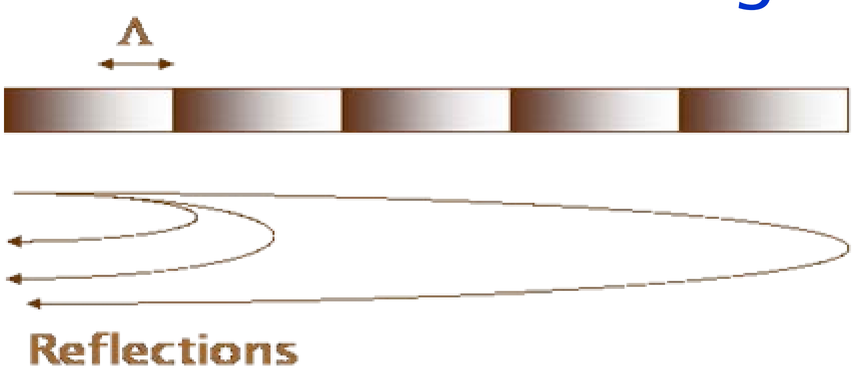
Reflection Grating

PRINCIPLES OF OPERATION

- Two waves traveling in opposite in fibre core with β_0 and β_1 (transmitted and reflected) superimpose each other if they meet BRAGG PHASE MATCHING CONDITION as:

$$|\beta_0 - \beta_1| = 2\pi/\Lambda$$

where Λ = Period of the grating

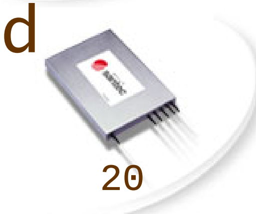


- Energy from the forward propagation mode of a wave at the *right* wavelength coupled into the backward propagation mode

- Light wave propagating from left to right (forward) and being reflected (backward), superimpose each other if:
  - $|\beta_0 - (-\beta_0)| = 2\beta_0 = 2\pi/\Lambda \Rightarrow \beta_0 = \pi/\Lambda$
  - $\beta_0 = 2\pi\, n_{eff}/\lambda_0$ (λ_0 = Wavelength of the incident wave)
  - n_{eff} = Effective refractive index of the fiber
  - $\lambda_0 = 2\, n_{eff}\, \Lambda$ since $\Lambda = \pi/\beta_0$

$$\lambda_0/2 = n_{eff}\,\Lambda$$

- λ_0 is the BRAGG WAVELENGTH that is reflected back by the gratings, all other wavelengths are transmitted straight

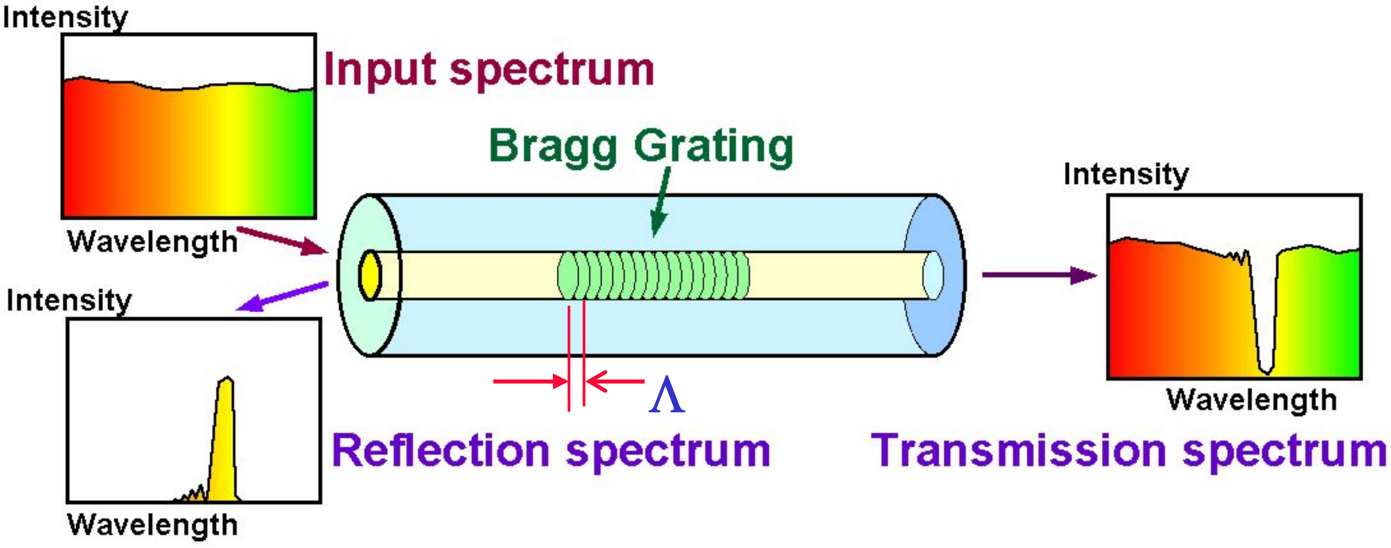


Fiber Bragg Gratings (FBG)

- FBG is a periodic refractive index variation (**Period Λ**) written along the fibre (single-mode) core using high power UV radiation.

- All the wavelengths statisfying the condition $\lambda_0 = 2\,\Lambda\, n_{eff}$ are reflected

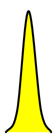
- If the optical period is λ_0 / 2, the grating reflects wavelength λ_0 selectively. Useful in filtering communication channels in or out.

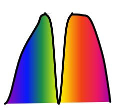


Fiber Bragg Gratings (FBG)

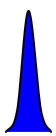
Grating pattern etched into body of fibre

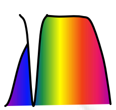
wavelength





For a given grating period a particular wavelength (frequency) of light is reflected. In this case yellow light will be reflected

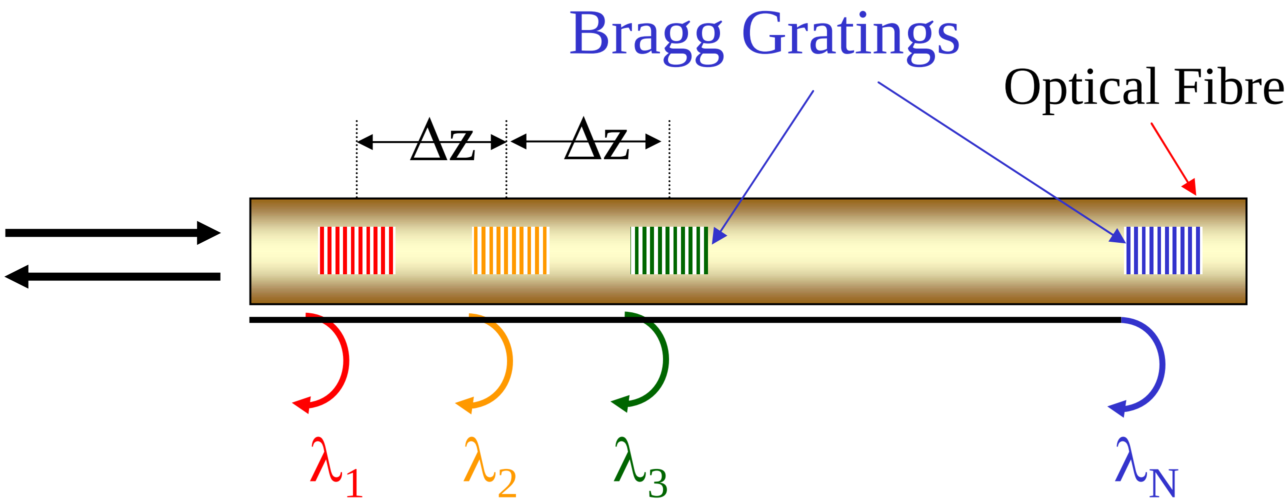




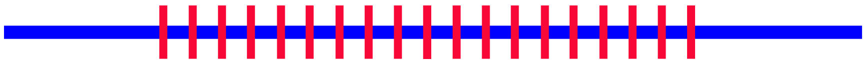
If the grating spacing is changed (e.g. reduced due to compression of the fibre or a drop in temperature} the wavelength of the reflected light changes. In this case it becomes higher and reflects blue light

In practice the colour shifts will be much finer than those illustated

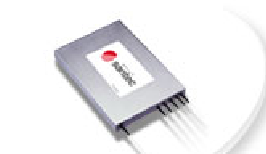
Fiber Brag Gratings (FBG)



- **Regular interval pattern:** reflective at *one* wavelength
  - Notch filter, add / drop multiplexer (see later)

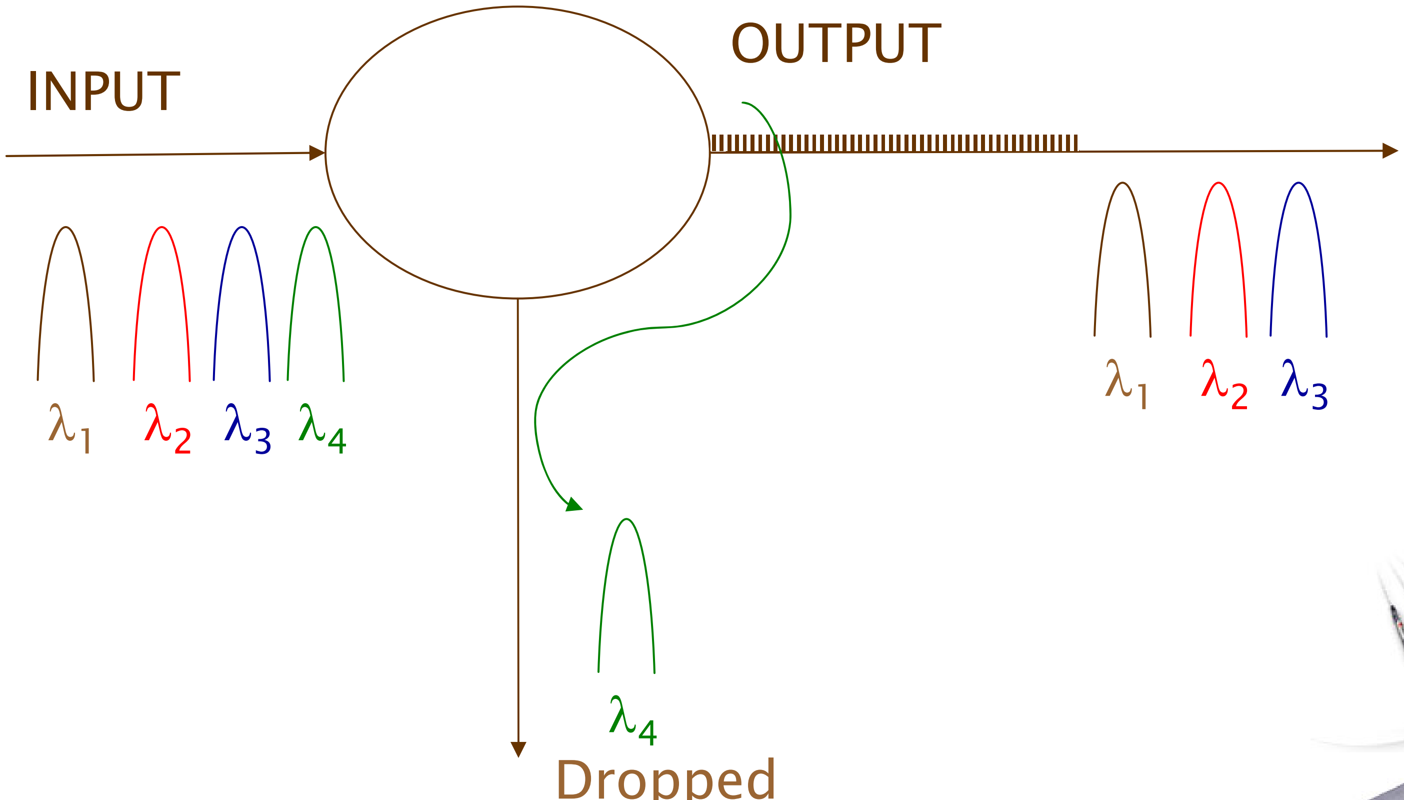


- Increasing intervals: “chirped” FBG compensation for chromatic dispersion



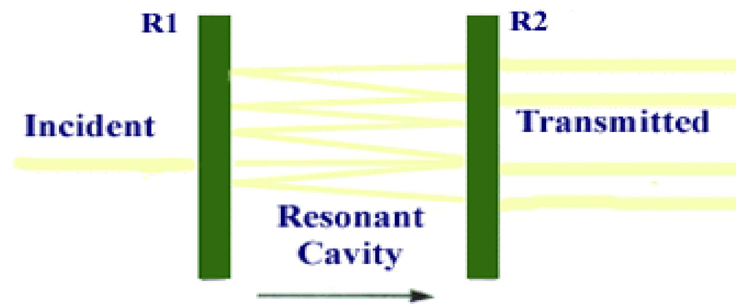
APPLICATION

ADD DROP MULTIPLEXERS



FABRY PEROT RESONATOR

- Made up of two mirrors facing each other with a cavity
- When light is incident on one mirror, the light
  - Either reflects or
  - Is transmitted through the other mirror
- The light that is reflecting inside the cavity interferes on subsequent reflections
- The distance and the wavelength determine if this interference is constructive in which the intensity of light that is transmitted increases



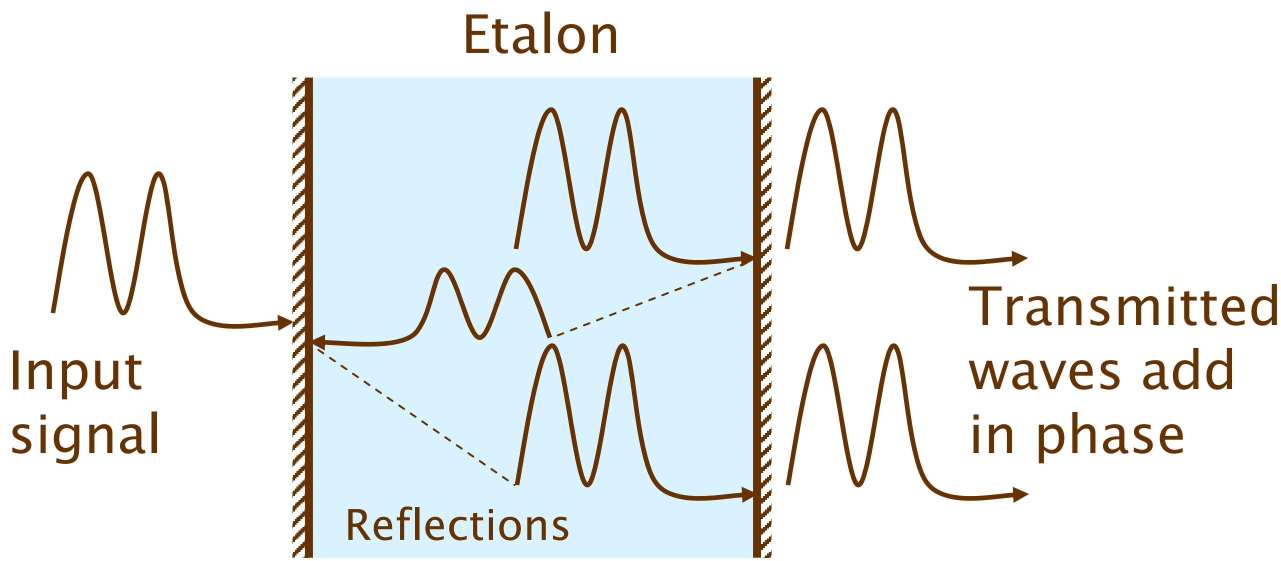
- Or destructive in which case the intensity of the light that is reflected decreases

PRINCIPLE OF OPERATION

- A composite signal is injected into the cavity
- After one pass through the cavity, part of the light leaves through the right face and part is reflected
- For those wavelengths for which the following condition is true, i.e.,
- $L_{cavity} = n\lambda/2$ λ = Incident wavelength
- L_{cavity} = length of the cavity $n = 1,2,\ldots$

- All the transmitted waves are added in phase
- Such wavelengths are termed as resonant wavelengths of the cavity

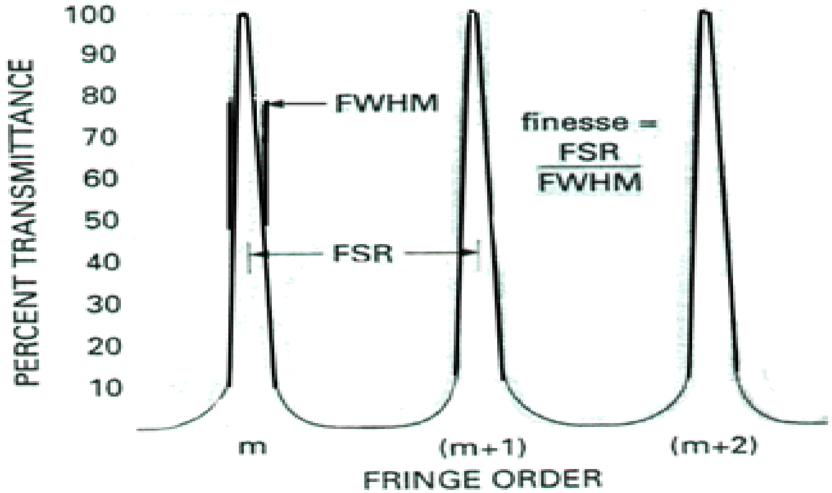
OPERATION

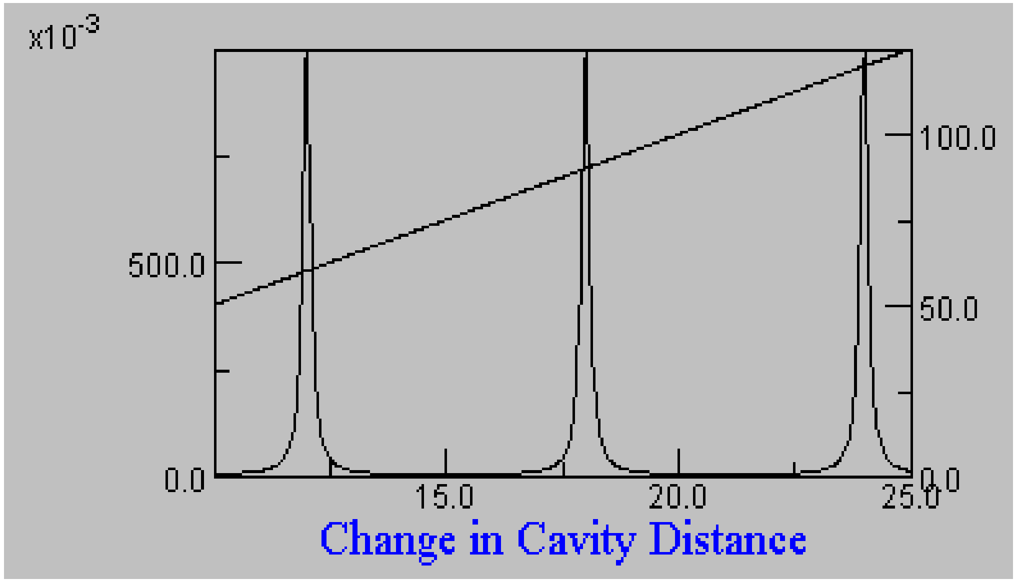


Simulations:

http://www.ee.buffalo.edu/faculty/cartwright/java_applets/cavity/FabryPerot/index.html

TRANSMISSION CHARACTERISTICS





EFFECT OF MIRROR TILT

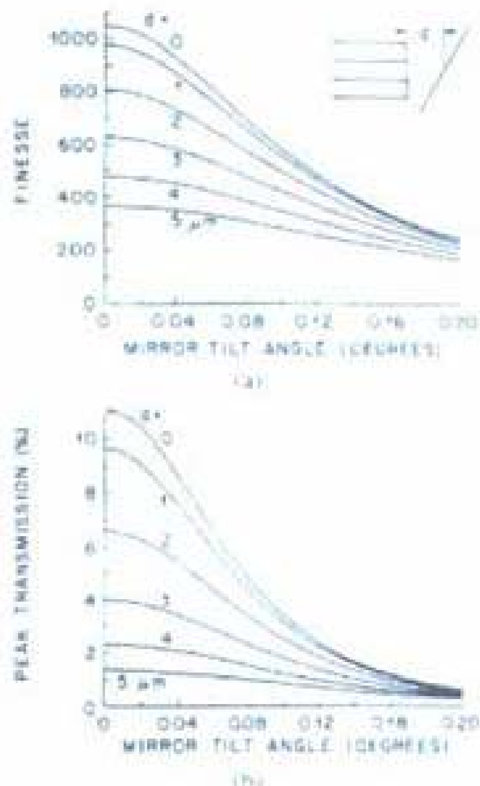


Fig 4-5: Effect of mirror tilt on the finesse and the transmiivity

EFFECT OF FRONT FACE CURVATURE

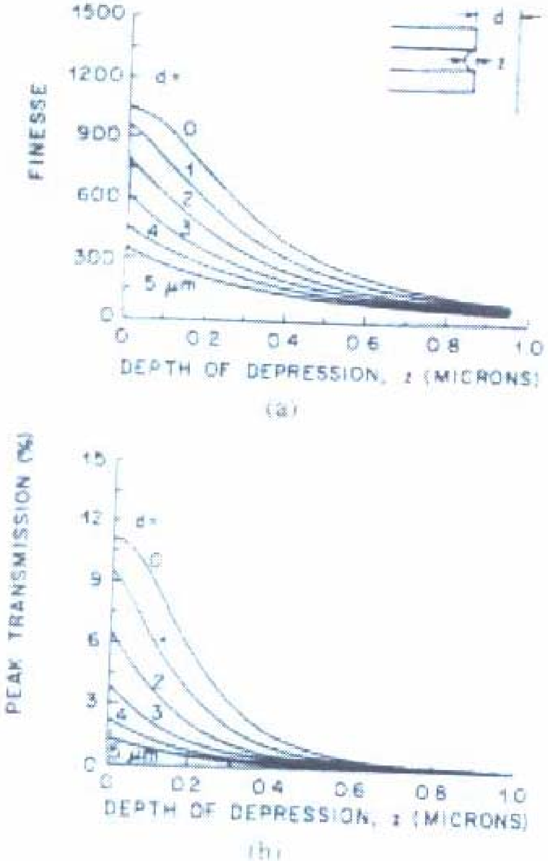
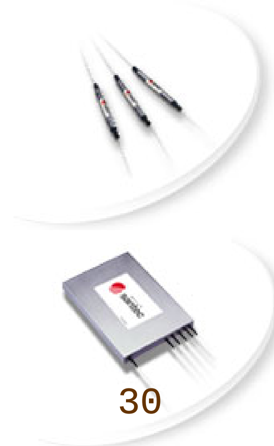


Fig 4-6: Effect of curvature of the end face on the two primary characteristics



EFFECT OF MIRROR REFLECTIVITY

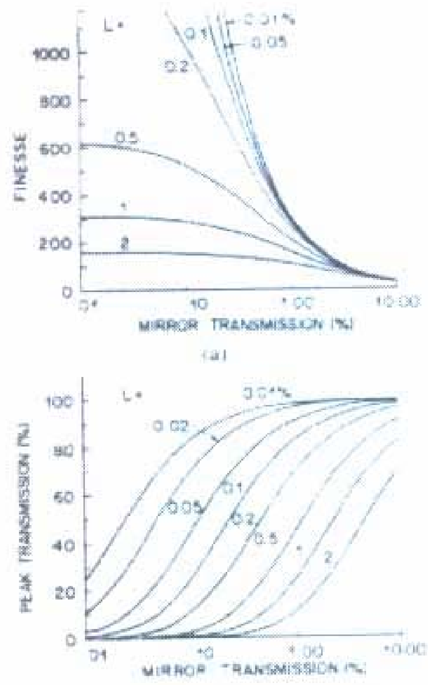
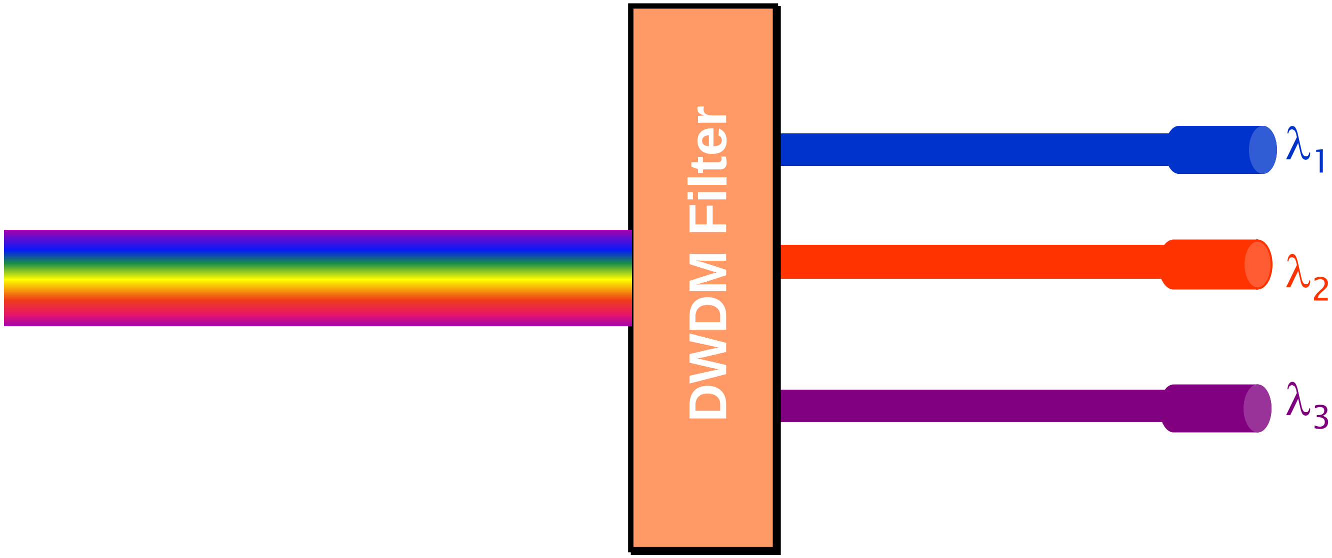


Fig 4-4: Transmission through the F-P with various reflectivities

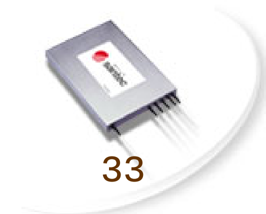
APPLICATION
RECEIVER FILTER

- Fabry–Perot filters are the choice for fixed wavelength filters such as receiver filters



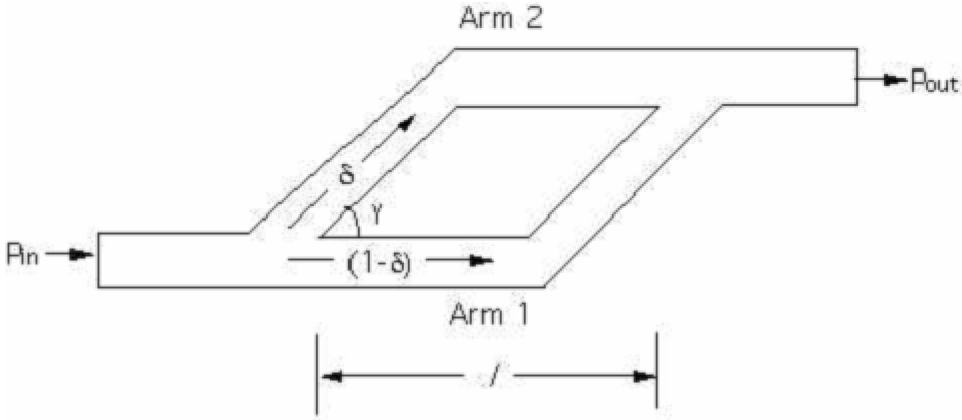
MULTILAYER DIELECTRIC THIN-FILM FILTERS

- Mirrors are coated using deposition schemes on the two ends of a fiber of a particular length (remember that the length determines the wavelength transmitted)
- Multiple cavities can be spliced together to form multilayered thin filmed resonators
- What is the advantage of having multiple cavities??
- Passband becomes flatter and skirts have higher roll-offs



PRINCIPLE CONCEPT:

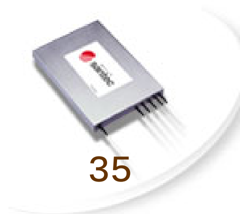
- Many wavelengths traversing multiple routes of different wavelengths shall interfere differently
- A wavelength that interferes the MOST CONSTRUCTIEVELY shall be transmitted with the maximum intensity, others would die out



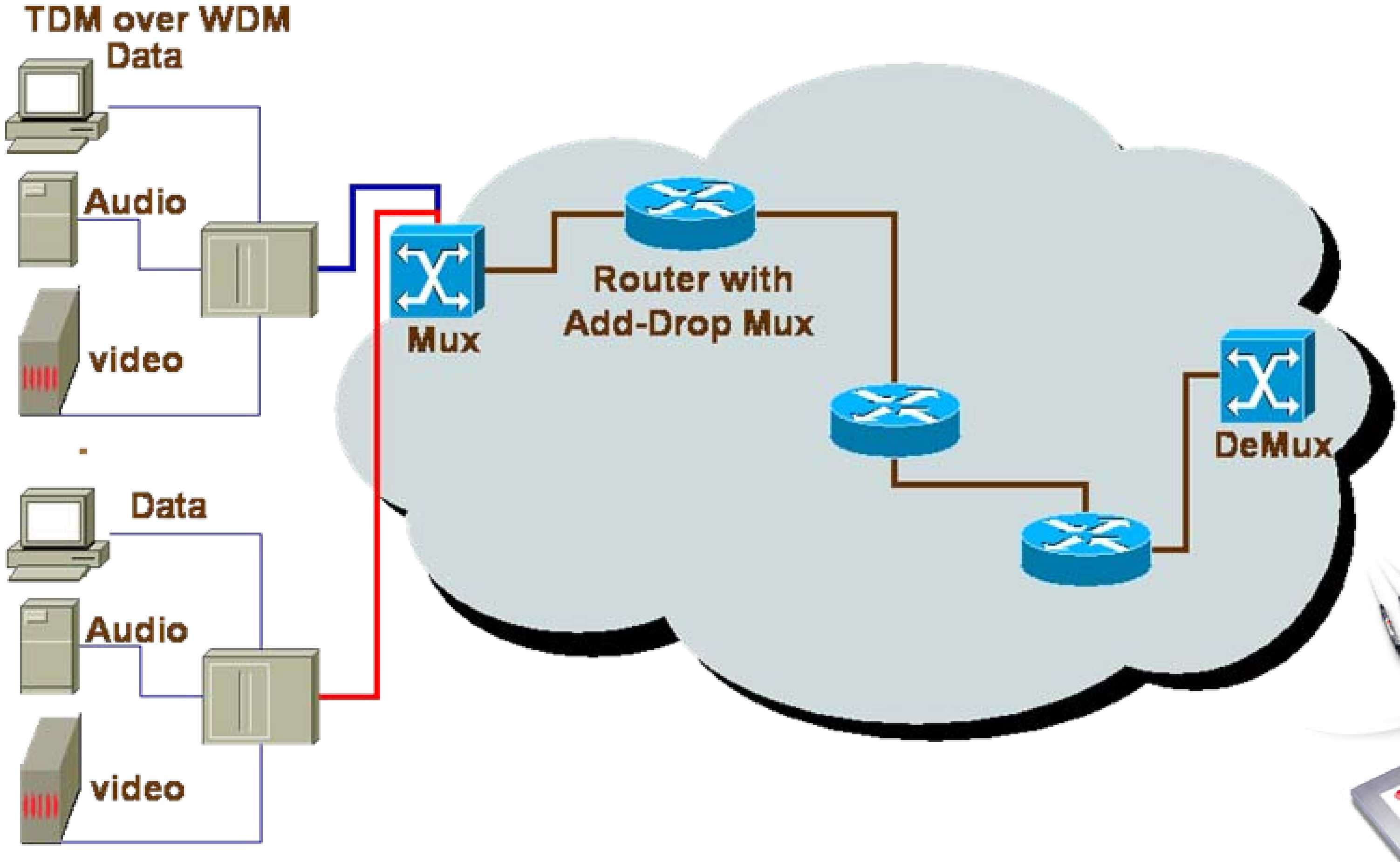
TUNING OF OPTICAL FILTERS

Tuning of the optical filters can be achieved using either of the following schemes

1. TEMPERATURE COEFFICIENT: Change in refractive index by varying the temperature coefficient allows us to tune-in with the desired wavelength
   - Equally useful in Bragg and Fabry-Perot phenomena
2. PIEZO-ELECTRIC PHENOMENON: Vary the length of the cavity using Piezo-Electric Devices
   - Typically used in All-Fiber Fabry-Perot Filters
3. ACOUSTO-ELECTRIC TRANSDUCERS: Using Acoustic (sound waves of lower order) waves to create periodic perturbations
   - Used to create Bragg Phenomenon



VARIOUS TIERS OF APPLICATIONS OF OPTICAL FILTERS



CUTTING EDGE RESEARCH FOCUS

- Most of the implementations in Add-Drop Mux, Optical Tunable Filters etc., is based on All-Fiber low cost technology
- Possible area of research is to improve Finesse and no of wave lengths in the Low Dispersion Window for Soliton Communication

Filter Economics

High-pass Filters

OF2-WG305	pass >305 nm	square 25.4 x 25.4 x 3 mm	$50
OF2-GG375	pass >375 nm	square 25.4 x 25.4 x 3 mm	$50
OF2-GG395	pass >395 nm	square 25.4 x 25.4 x 3 mm	$50
OF2-GG475	pass >475 nm	square 50.8 x 50.8 x 3 mm or square 25.4 x 25.4 x 3 mm	$50
OF2-OG515	pass >515 nm	square 25.4 x 25.4 x 3 mm	$50
OF2-OG550	pass >550 nm	square 25.4 x 25.4 x 3 mm	$50

Balancing Filters

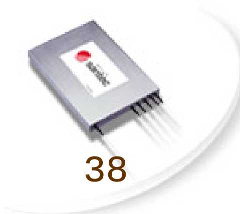
OF2-FG3	enhance blue and red	square 25.4 x 25.4 x 3 mm	$50
OF2-BG34	enhance blue and red	square 25.4 x 25.4 x 3 mm	$50
OF2-BG34R	enhance blue and red	round 12.7 mm OD	$50

Bandpass Filters

OF2-KG3	>325 nm and <700 nm	square 25.4 x 25.4 x 3 mm	$50
OF2-U360	>340 nm and <380 nm	square 25.4 x 25.4 x 3 mm	$50
OF2-RG780	>780 nm and 50% transmission <2.7 µm	square 25.4 x 25.4 x 3 mm	$50

Filter Kit for use with LS-1 Light Source

OF2-LS	BG-34, GG395, OG550, Teflon diffusers	$100



- http://www.oceanoptics.com/products/filters.asp

FURTHER READING

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