Tunable Receiver Technologies

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Outline

- Why Tunable Receiver
- What is an ideal Tunable Filter (TF)
- Evaluation Parameters of TF
- Major Types of TF
- Summary

Why Tunable Receiver?

- Tunable optics enable wavelength tuning features in optical communications
- Tunable receivers work with tunable transmitters to provide access network flexibility and extendibility on legacy ODN
- "Colorless" ONU is highly desired for low OPEX and high volume applications

Tunable Receiver = Tunable Filter + Receiver

- Tunable Filter(TF) is an important sub-assembly of a Tunable Receiver.

What is an ideal TF?

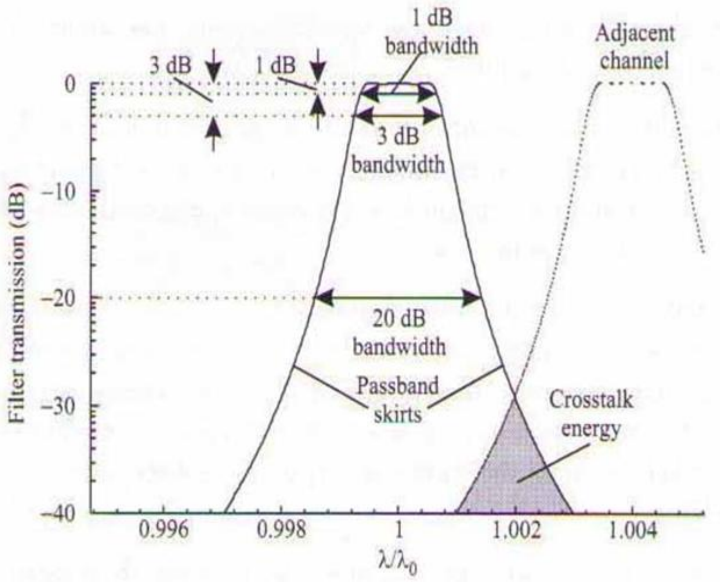
- **Ideal TF:** A device which can isolate an arbitrary spectral band at an arbitrary wavelength over a broad, continuous spectral range, preferably with a response function which is identical in form at all wavelengths.

Evaluation Parameters of TF (1 of 2)

- **Insert Loss (IL):** ratio of output optical power and input optical power in dB unit, the lower the better.
- **Polarization Dependent Loss (PDL):** ratio of the maximum and minimum transmission of an optical device with respect to all polarization states. The polarization dependence of the transmission properties of optical components has many sources, in unit of dB, the lower the better.
- **Return Loss:** logarithm of the ratio of input optical power and returned optical power at the same test point, in unit of dB, the lower the better.
- **Tuning Speed:** generally classified as s, ms, ns, etc.
- **Tuning Range:** in unit of nm, the larger the better.
- **High volume production capacity:** depending on manufacturing technology.

Evaluation Parameters of TF

- **Passband:** the passband should be as flat as possible to reduce the influence of transmitting wavelength shift, the larger of the 1dB bandwidth the better, edge of the passband should be steep enough to reduce the adjacent channels’ crosstalk, crosstalk’ s ideal value is -30~-20dB.
- **Control Mechanism:** wavelength tuning and stable mechanism, affecting the tuning speed, precision and wavelength stability.
- **Power Consumption:** the lower the better.
- **Cost:** the lower the better.
- **Size/Integration capability:** the smaller size or the easier integration capability the better.



Passband character of TF

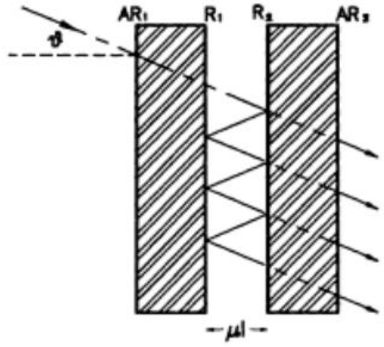
Major Types of TF

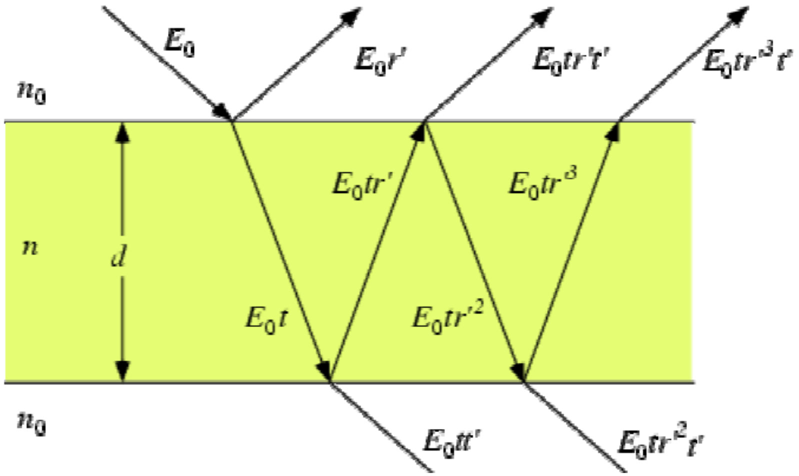
- **Fabry-Perot filter**
  - Thermal Optical FP TF
  - Liquid Crystal FP TF
  - MEMS FP TF
- **Waveguide Filter**
  - MZI Filter
  - Micro Ring Filter
- **Micro-motor Filter**
  - Linear Variable Filter
  - Angle Adjustment Filter
  - Cavity Length Adjustment Filter

■Fabry-Perot Filter

Basic Principles I

- Fabry-Perot filter is made of a transparent plate with two reflecting surfaces, or two parallel highly-reflecting mirrors
- Light entering the cavity undergoes multiple reflections. At the resonant wavelengths, the resultant reflected beam destructively interferes with the light reflected from the first plate cavity boundary and all the incident energy, in the absence of absorption, is transmitted.





Basic Principles II

According to the principle of multi-beam interference, the intensity of the transmitted light is:

$$I_t = \frac{(1-R)^2}{(1-R)^2 + 4R\sin^2\frac{\delta}{2}} I_0$$

δ is the optical path phase difference of two adjacent light beam:

$$\delta = \frac{4\pi}{\lambda} nd\cos\theta + \pi$$

Wherein R is the light intensity reflectance of the two end faces, here assuming the reflectance of two faces is the same, if different, R is the average of the two reflectance.

R1,R2 are the reflectance of the two faces respectively;

$$R = \sqrt{R_1 R_2}$$

n is the refractive index of FP cavity;

d is the thickness of the cavity;

θ is the light inclination angle in the FP cavity.

The transmission spectrum of FP cavity usually has a series of equally spaced transmission peaks, FSR is used to define the distance between two adjacent resonance peaks:

$$FSR = \frac{c}{2nd\cos\theta}$$

Subtypes

The m-class peak transmission wavelength is:

$$\lambda_m = \frac{2nd}{m}\cos\theta$$

Tuning parameters *n*, *d* or θ can change the peak wavelength.

Tuning Parameter	Types
n	Thermal optical FP TF, Liquid crystal FP TF, Electrical optical FP TF, etc.
d	MEMS FP TF , Micro-motor FP TF, etc
θ	Angle adjustment FP TF ,etc

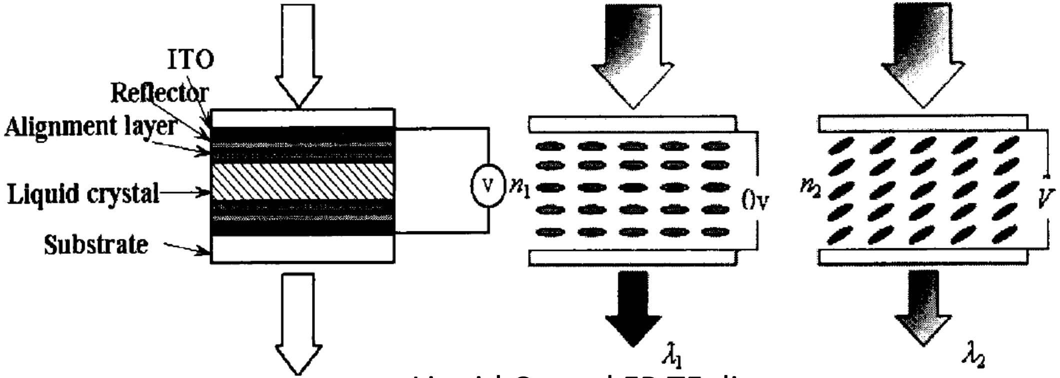
- Currently FP tunable filters such as thermal optical filter, liquid crystal filter and MEMS filter have seen product applications, and are widely used in optical communications.

Subtype 1 --- Thermal Optical

- **Pros:**
  - Small size, easy for integration
  - Low cost materials, adaptive high volume application
  - Tuning range can reach 40nm, or larger, depending on different structures
  - Successful industry production experience, mature industrial chain.

- **Cons:**
  - Tuning and stabilizing the wavelength by heat, need to reduce power consumption
  - Slow tuning speed, depending on the power of the heater and heating method.

Subtype 2 --- Liquid Crystal



Liquid Crystal FP TF diagram

- Liquid crystal FP TF has been applied in optical communications, it is used in OCM, OADM, WDD devices.
- **Pros:**
  - Mature technology, wide application, low cost, mature industry chain
  - Tuning range can reach 30nm
  - Low power consumption
  - Fast tuning speed
- **Cons:**
  - Polarization dependent, Large size
  - Temperature sensitivity, need temperature stability device, such as thermoelectric cooler or heater.

Subtype 3 --- MEMS

■ MEMS FP TF is a promising technology. It is applied in optical communications and medical instruments

■ Pros:

- Fast tuning speed at μs level
- Large tuning range
- Small size
- Low power consumption

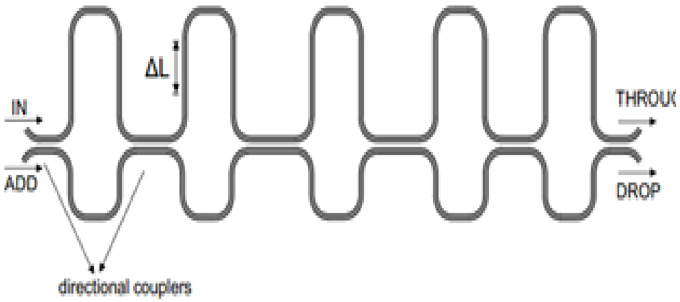
■Cons:

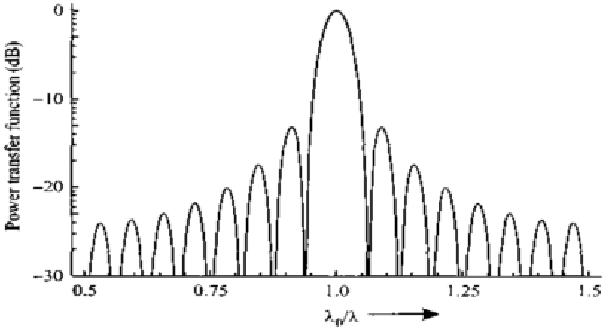
- Complex process, high cost, need to assess in high volume capacity
- Poor anti-shock performance

■Waveguide Filter

Subtype 1 --- MZI

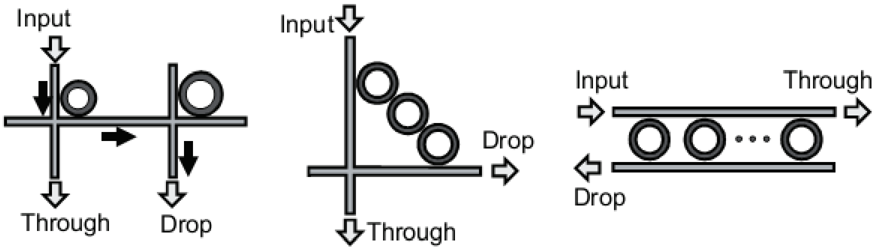
- Mach-Zehnder Interferometer (MZI) uses the optical path difference of different interference paths to decompose the target wavelength
- Transmission spectrum of single MZI is very wide, multi-MZI are cascaded to achieve narrow spectrum
- Large crosstalk
- Not suitable for large-scale application





Subtype 2 --- Micro Ring

- Based on resonator principle
- Multi-cavity/Cascade designed to achieve appropriate spectrum
  - The following are three cascade types: Cascading, Series Coupling and Parallel Coupling
- Less applications



(a) cascading (b) series coupling (c) parallel coupling

Topology	Advantages	Drawbacks
Cascading	Expansion of FSR, Reduction of crosstalk	Loss increase due to center wavelength mismatch
Series coupling	Expansion of FSR, Flattop pass band	Small fabrication tolerance
Parallel coupling	Flattop pass band	Small fabrication tolerance

Waveguide Filter--summary

■ **Pros:**

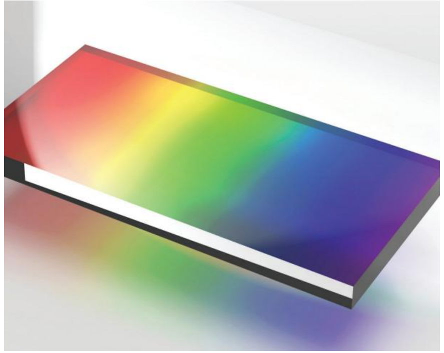
- Steep spectrum character, meeting 12.5GHz or narrower channel spacing requirement of DWDM application
- PLC-based implementation, good for large volume integrated photonics
- Many companies, research institutes and universities have participated in the related research areas

■ **Cons:**

- Large IL
- Low encapsulated error tolerance, high requirement of process, difficult for mass production

■Micro-motor Filter

Subtype 1 --- Linear Variable



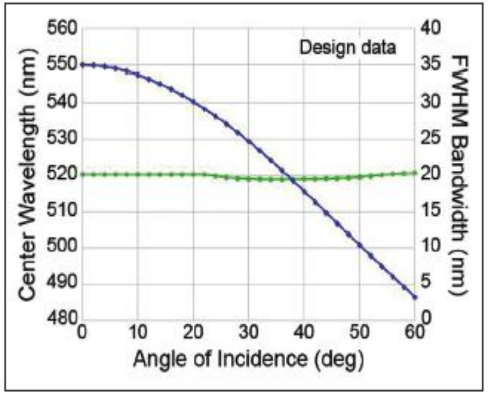
** REO company linear variable filter*

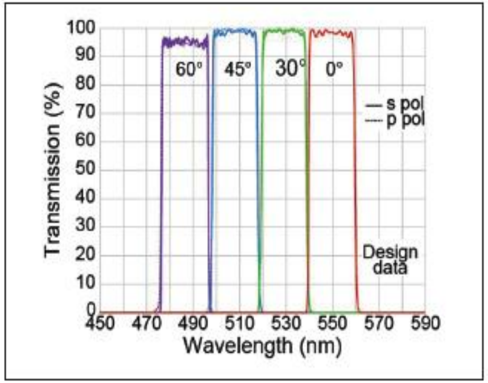
- Linear variable filter : transmission spectra changes with filter spatial location
- Technology is relatively mature
- Large tunable range
- Low insertion loss
- ms-level tuning speed
- Large FWHM(Full width at half maximum).
- Large size, difficult to integrate into TO
- High cost

Typical Bandpass Filter Specifications	
Materials	Optical glass,fused silica,silicon,sapphire
Wavelength Ranges	380nm-760nm,600nm-1100nm,1.3um-2.6um
Transmitted wavefront distortion	λ/10
Peak Transmission	60%
Bandwidth(FWHM)	1% of center wavelength
Linearity	0.5%
Attenuation	0.1%
Temperature range	-196℃ to 100℃
Humidity range	0 to 100%
Size range(length)	3mm to 150mm
Surface Quality	20-10
Clear Aperture	90%

Subtype 2 --- Angle Adjustment

- A special thin-film filter, adjusting incident light angle to adjust wavelength
- Technology is relatively mature
- Large tuning range(~80nm)
- Low insertion loss(~0.5dB)
- Large size
- High cost





Subtype 3 --- Cavity Length Adjustment

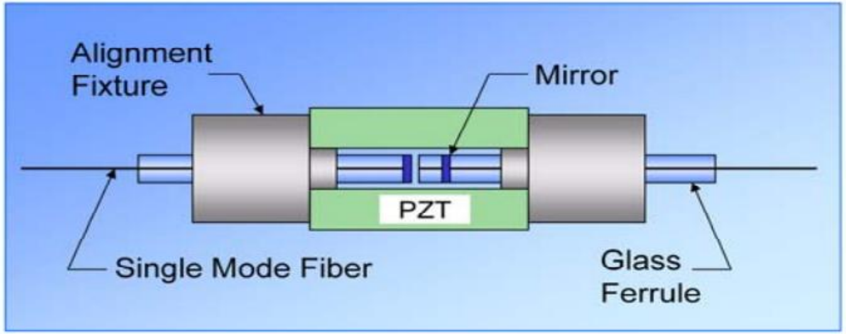


**Figure is from Micro Optics. Inc.*

- A special filter, by adjusting cavity length to adjust the wavelength
- Low Insertion Loss
- Thermally Stable
- High Reliability
- Large size

Micro-motor Filter--summary

- **Pros:**
  - Mature products, meet DWDM communication requirement, some technologies have been used in TF, OCM, OADM, WSS devices
- **Cons:**
  - Has to work with micro-motor, large size, difficult to miniaturization
  - High cost due to complex process

Comprehensive comparison of TF options

Filter Types		Tuning Range (nm)	IL(dB)	FWHM (nm)	Channel Spacing/ Isolation	Tuning Speed	Pwr[2]	Cost[2]	Size
Fabry-Perot	Thermal Optical FP Filter	40	2	<0.5	100GHz/25dB	s	Mid	Low	Small
	Liquid Crystal FP Filter	30	3	<0.5	100GHz/20dB	ms	Low	Mid	Mid
	MEMS FP Filter[3]	221	1.5	<0.5	100GHz/20dB	ms	Low	High	Small
Waveguide	MZI Filter[4、5]	15	4	<0.5	100GHz/10dB	µs	Mid	Mid	Small
	Micro Ring Filter[5]	20	5.2	<0.5	100GHz/60dB	ms	Low	Mid	Small
Micro-motor	Angle Adjustment Filter	80	0.5	<0.5	100GHz/25dB	ms	Low	High	Large
	Linear Variable Filter	380	2	CWL[1]*1%	100GHz/25dB	ms	Low	High	Large
	Cavity Length Adjustment Filter	60	2	<0.5	100GHz/20dB	ms	Low	High	Large

1) *CWL: Center Wavelength*
2) *Power and cost including TEC if required for extended temp. operation*
3) *Poor anti-shock performance*
4) Large crosstalk
5) Large IL

Summary

- Tunable filters facilitate wavelength tuning in optical access networks
- Multiple technologies are available to fulfill tunable wavelength receiving functions at the ONU side
- It's strongly recommended to refer to typical tunable filter performance when specifying NGEPON system wavelength tuning parameters.

Thank you!