Demultiplexers with ~10pm (1.25 GHz) 3dB Transmission Bandwidth Using Virtually Imaged Phased Array (VIPA)

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Outline

1. Hyperfine Wavelength Division Multiplexing (HWDM)

   A new technique to sub-multiplex DWDM

2. Virtually imaged phased array (VIPA) spectral dispersers

   Large angular dispersion > 1 deg/nm, low PDL and compact

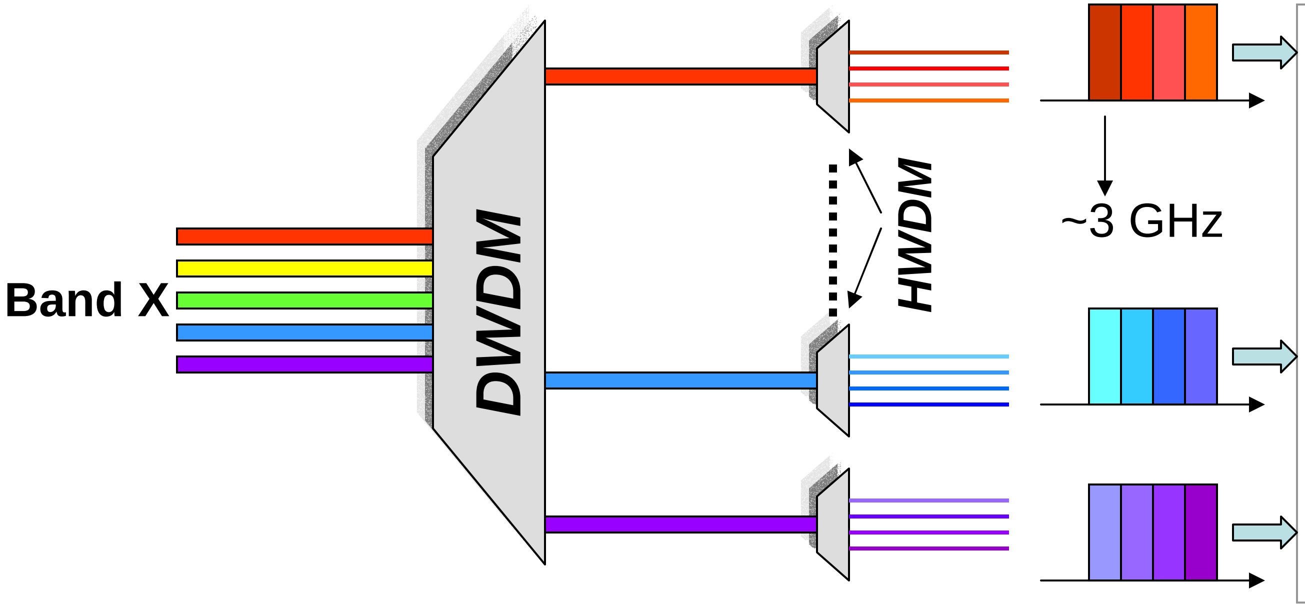
3. A diffraction analysis for the VIPA

   Predicts lineshapes with ~ 10 pm 3 dB bandwidth

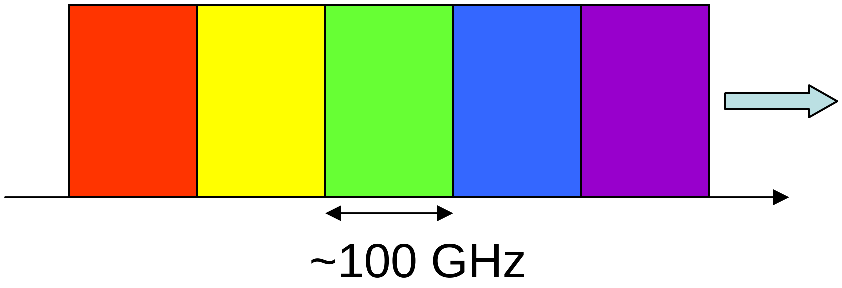
4. Hyperfine wavelength demultiplexing performance of the VIPA

   20 - 30 pm channel spacing, ~10 pm channel pass band, < =10 dB insertion loss

Hyperfine WDM



HWDM is a passive technology, and it can sub-multiplex DWDM to several GHz channel spacing. Novel optical spectral dispersers are crucial to HWDM. VIPA is a very promising candidate.



Current DWDM technology, based on Bragg gratings, AWG, etc, typically operates with hundreds or tens of GHz channel spacing.

(See also http://www.essexcorp.com/products.html)

HWDM Application

Radio frequency (RF) photonics

12.4-37.2 GHz RF waveforms generation by selecting and beating different longitudinal modes of a 12.4 GHz mode locked semiconductor laser through HWDM technology from Essex corp.
(P. J. Delfyett, etc, IEEE PTL, 2002)

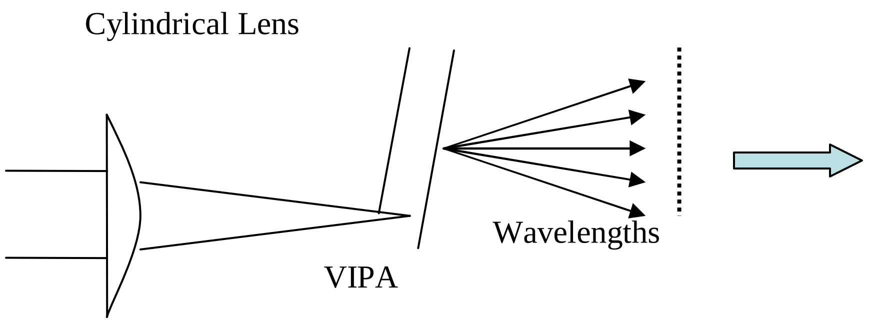
Laser rate multiplication

HWDM was used to select every fifth of the spectral modes from a 10 GHz mode locking laser to obtain a 50 GHz laser.
(M. Currie, etc, Post Deadline, CLEO, 2003)

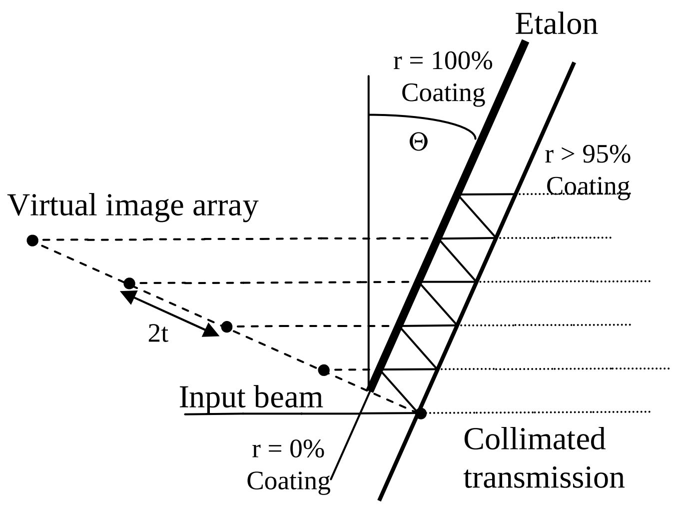
Potential applications in optical communication

1. Increase flexibility for providing bandwidth granularity
2. Subcarrier multiplexing (SCM) for high speed optical communications
3. Mitigate the PMD by lower bit rate in HWDM channels while maintaining total bit rate
4. Low chromatic dispersion due to hyperfine channels.

VIPA Structure



Scheme of a VIPA spectral disperser

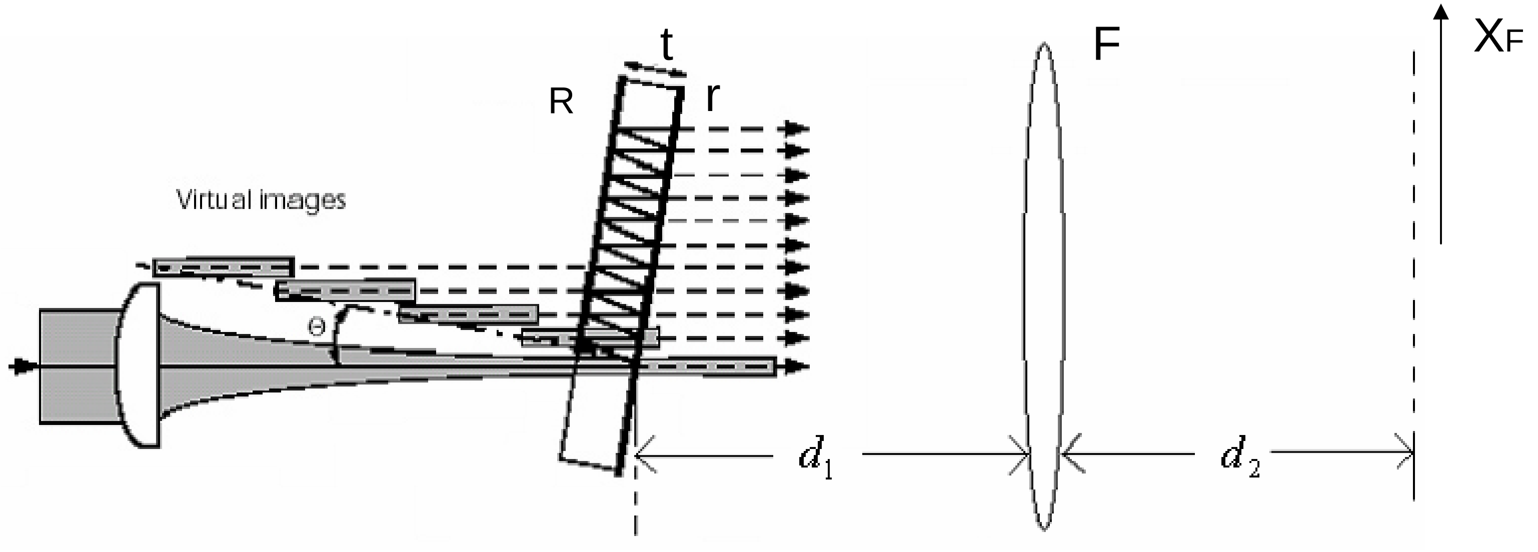


The concept of virtually imaged phased array

(M. Shirasaki, Optics Letters, 1996)

- VIPA provides larger angular dispersion (> 1 deg / nm) than gratings.
  Low polarization dependent loss, compactness, potential low cost
- Applications:
  Dispersion compensation (M. Shirasaki, OFC, 2001)
  Pulse shaping and RF-AWG (S. Xiao, CTuGG, CLEO 2004)
  HWDM (Our current work)

Diffraction Analysis



(S. Xiao, etc, CWP6, CLEO 2003)

When $d_2 = F$, symmetric spectra are obtained, and the spectra has the minimal 3dB transmission bandwidth (FWHM) for a fixed incident angle. In this case, the field at the origin of the back focal plane is

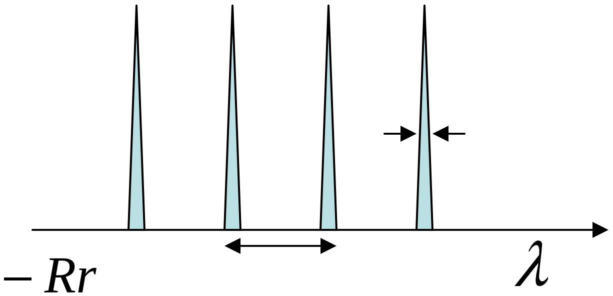
$$\boxed{E_{out}(x_F = 0, \lambda) \propto \sum (Rr)^n \exp\left[-ikn2t\cos(\theta_i)\right]}$$

3dB Transmission Bandwidth

$$E_{out}(x_F = 0, \lambda) \propto \sum (Rr)^n \exp\left[-ikn2t\cos(\theta_i)\right]$$

Assuming a large number of beam spots at small incident angles

$$I \propto |E|^2 \propto \frac{1}{(1-Rr)^2 + 4Rr\sin^2\left[kt\cos(\theta_i)\right]}$$

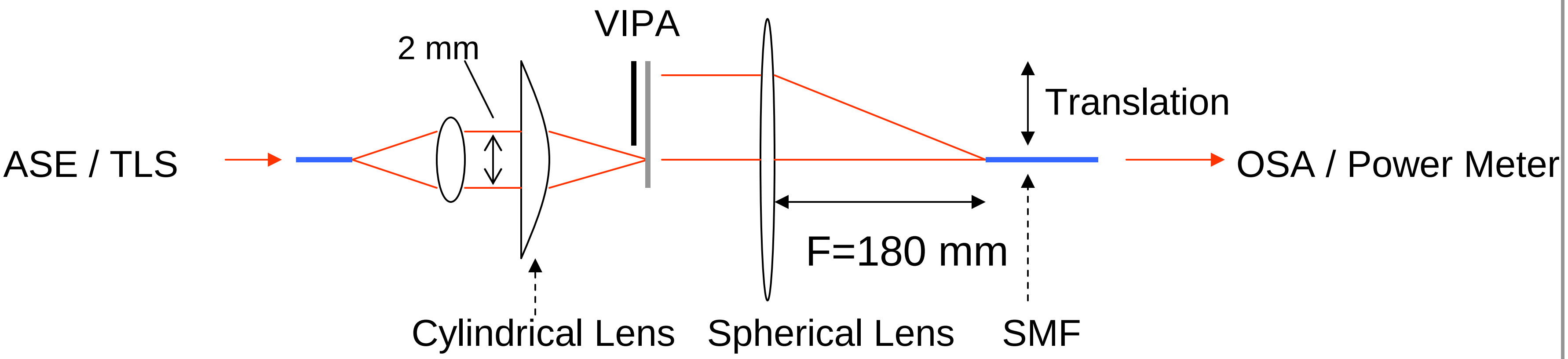


$$FSR = \frac{\lambda_0^{\ 2}}{2t\cos(\theta_i)} \qquad FWHM = \frac{\lambda_0^{\ 2}}{2\pi t\cos(\theta_i)} \frac{1-Rr}{\sqrt{Rr}}$$

$$Finesse = \frac{FSR}{FWHM} = \frac{\pi\sqrt{Rr}}{1-Rr}$$

Numerical example for small incident angles $\cos(\theta_i) \sim 1$
$\lambda_0 \sim 1550$nm, t ~ 1.5 mm (100 GHz) for an air VIPA, Rr ~ 95%,FWHM ~ 13 pm;
For a 50 GHz solid VIPA, same reflectivity, FWHM ~ 6.5 pm.

Experiment Setup



ASE: Amplified Spontaneous Emission

TLS: Tunable Laser Source

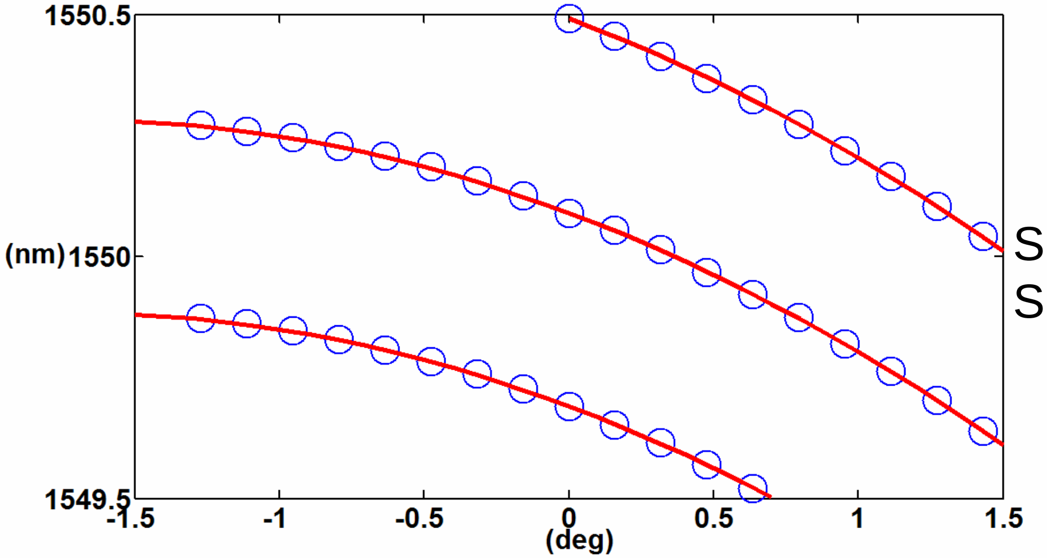
SMF: SMF-28, 9/125 um

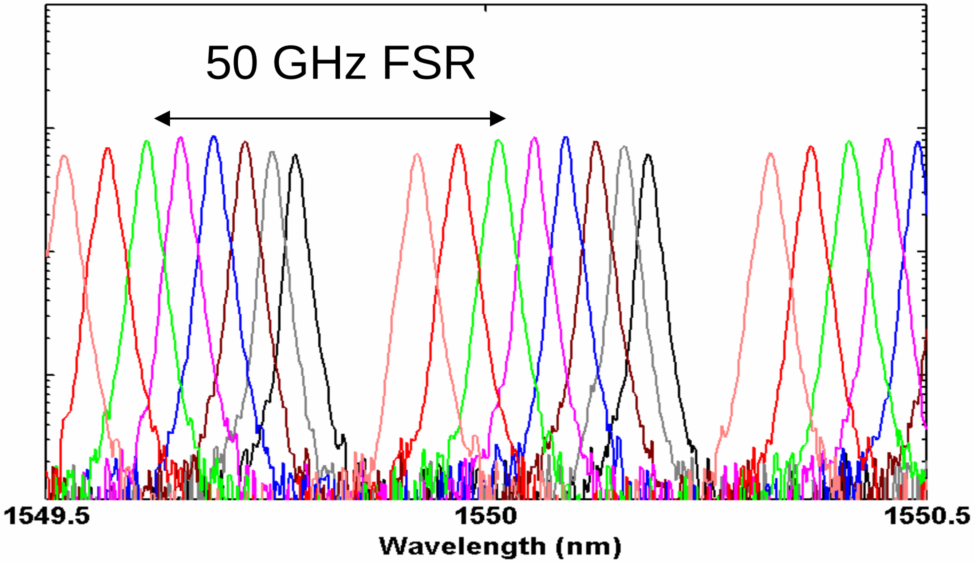
OSA: optical spectrum analyzer (10 pm resolution)

ASE is used to demonstrate the multiple channel demultiplexing transmission spectra measured by OSA at different output angles.

TLS with 1pm wavelength resolution is used to scan the filter lineshape, and the insertion loss is measured simultaneously.

Demultiplexing Channels





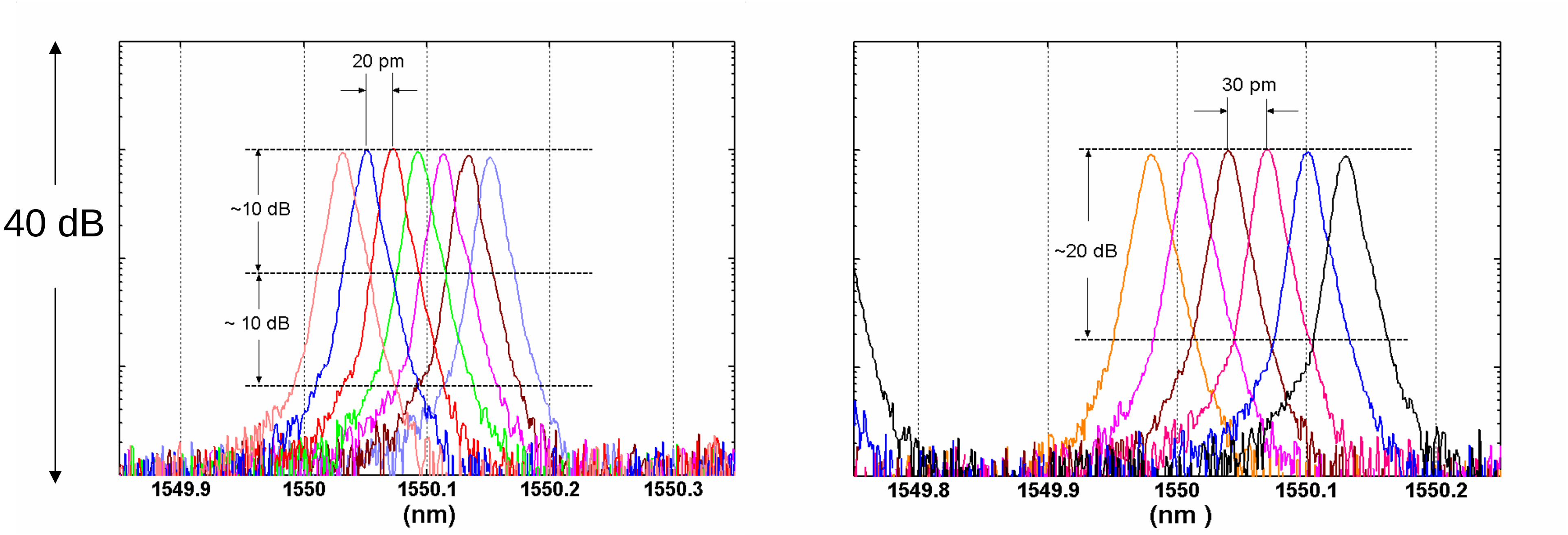
1. A uniform shift of the fiber with a step of 0.16 degrees.

2. 3dB bandwidth:
(1) OSA (10 pm resolution)
100 GHz→17 pm
50 GHz → 13 pm

(2) TLS (1 pm resolution)
100GHz →12 pm
50 GHz → 7 pm

S. Xiao, in press, IEEE JQE, April/2004
S. Xiao, CThCC, CLEO 2004

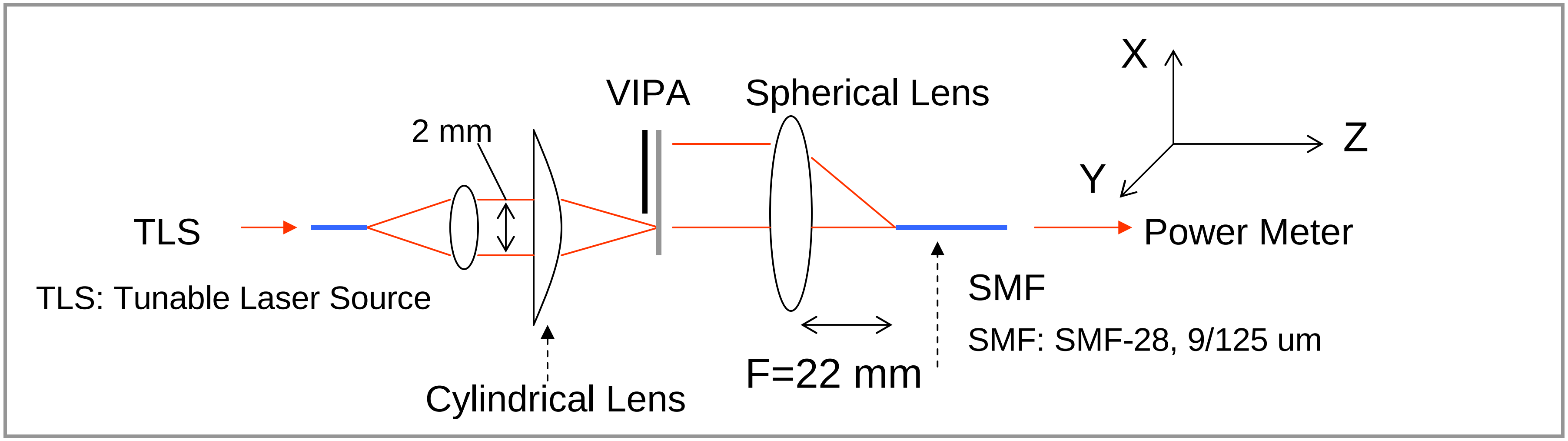
Uniform Channel Spacing



The step size is 300um (0.1 deg) and 450um (0.15 deg) for 20 pm and 30 pm channel spacing respectively, and the OSA has a 10 pm resolution. A 50 GHz solid VIPA is used.

Uniform channel spacing with uniform angle spacing is demonstrated as constant angular dispersion can be obtained around zero output angle,

Insertion loss optimization



Potential main Losses:

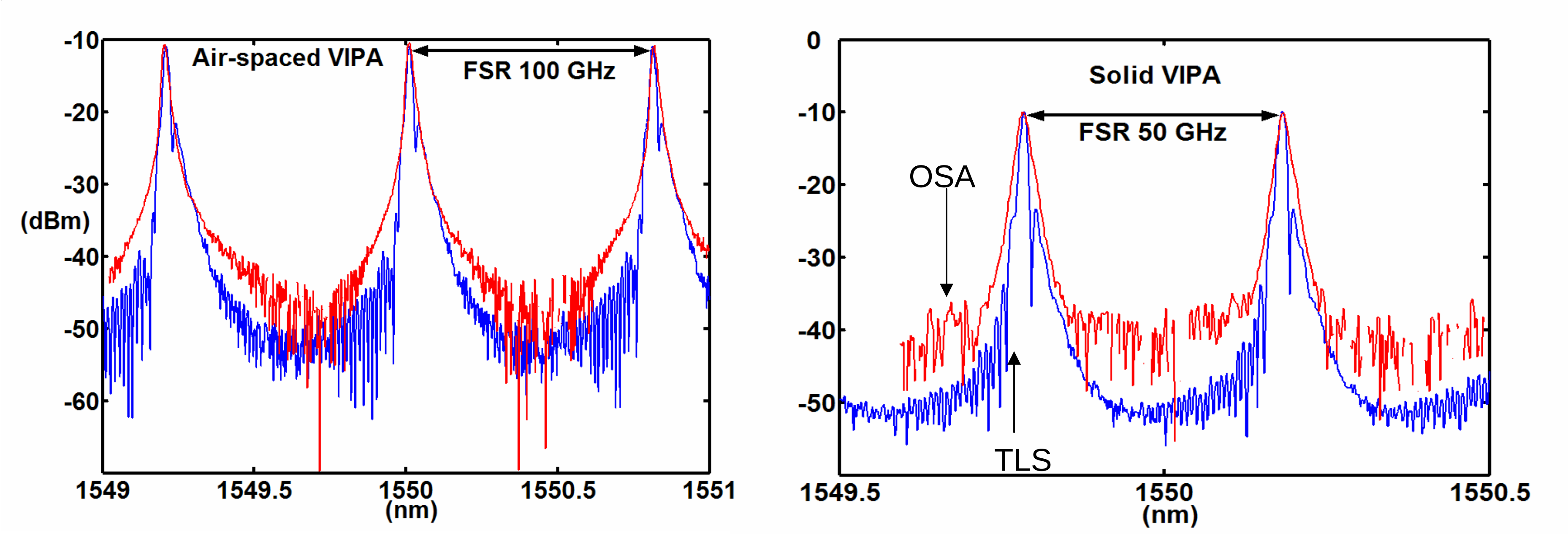
1. Beam coupling into bare fiber SMF-28, 9/125 um

2, Beam clipping at the incident window (controlled by beam injection).

F= 180 mm→ large focusing spot → relative large insertion loss
F=22mm → small focusing spot → much improved insertion loss

Including cylindrical lens for focusing instead of one spherical lens in our current work should further reduce insertion loss.

Data scanned by tunable laser source



	-1 dB Bandwidth	-3 dB Bandwidth	-20dB Bandwidth	Insertion Loss
Air spaced VIPA (100 GHz)	9 pm	12pm → 17 pm	112 pm	10~10.5 dB
Solid VIPA (50 GHz)	6 pm	7pm → 9 pm	56 pm	9~9.5 dB

Summary

- We present a theory using diffraction analysis for the VIPA demultiplexer, and our theory agrees well with our experiments
- We demonstrate ~1.25 GHz at 1.55 um 3 dB demultiplexing pass band of VIPA with 100 GHz and 50 GHz FSR.
- We demonstrate a center channel insertion loss around 10 dBm while maintaining a ~1.25 GHz 3dB bandwidth
- Our study demonstrates HWDM performance for the VIPA