Optical Technique for 5G Wireless Access

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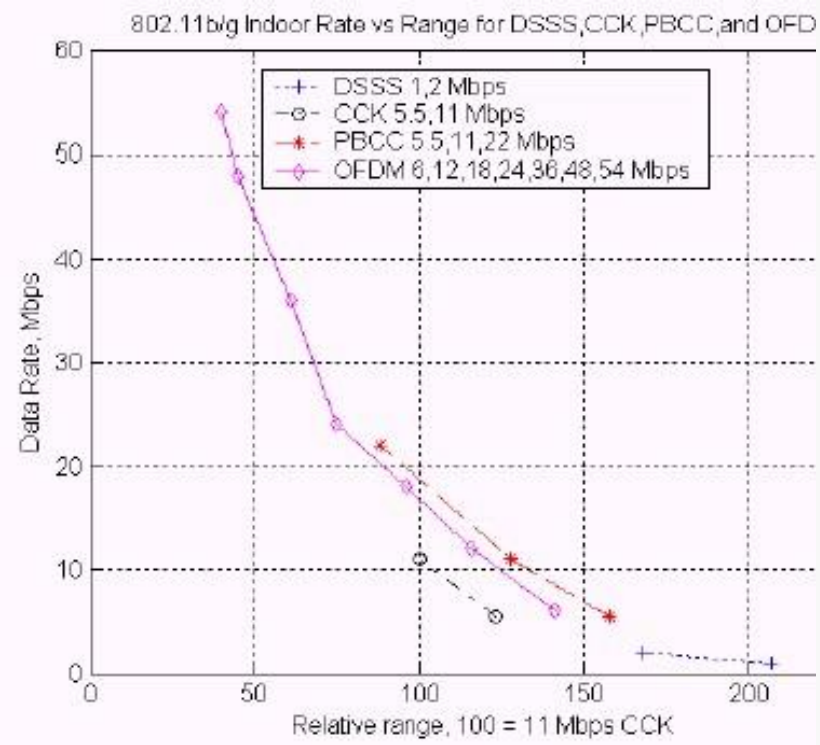
A Major Challenge in 5G

- 5G envisions up to 10 Gb/s
- The air interface has to be very short at Gb bit rates, due to limits in basic physics (very low energy per bit)
- $E_b = \frac{Transmit\ Power}{Baud\ Rate}$

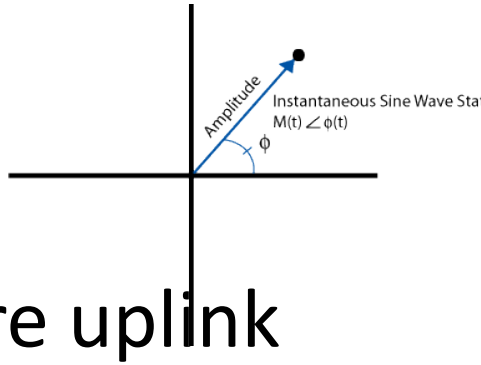


Distance drastically drops with the bit rate - Pasquale Romano, 2Wire

Optical Techniques

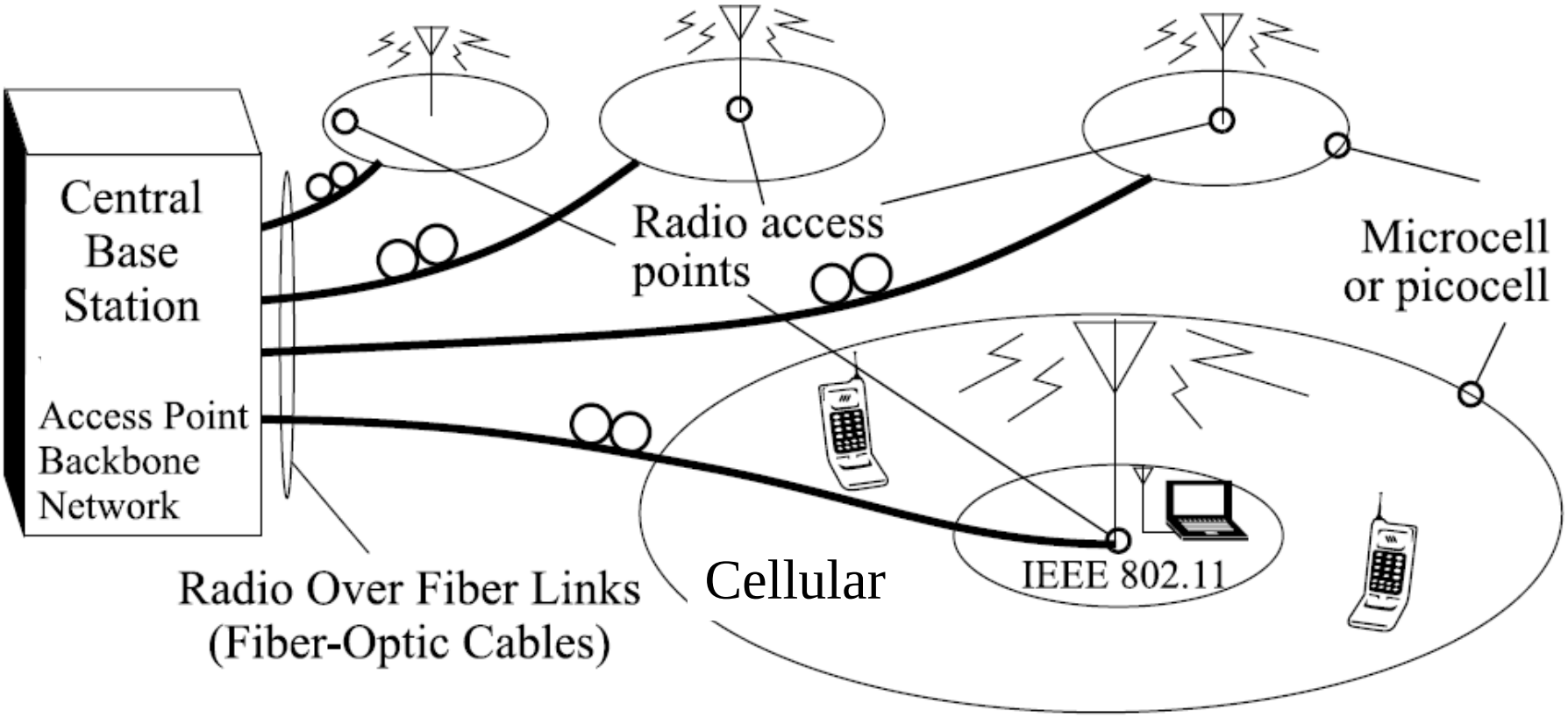
- Bring the radio access points closer to the user
  - Fiber-Wireless (Radio over Fiber) systems
  - Optical feeders for distributed antennas
  - Integration with PON and, HFC networks
- Optical wireless techniques
  - Visible light communications (VLC)
  - Infrared wireless communications
  - Point to point/Distributed
  - Indoor/outdoor

Key Issues in OW



- Primarily for downlink – IOT needs more uplink
- Line of sight and short range
- Very short channel coherent time (outdoors)
- Detection issue. Optical reception is difficult than RF receivers
- High level of ambient light noise (SNR < 0)
- Intensity modulated optical signals are scalars.
  - Only the **Amplitude** can be changed (Unipolar) while radio signals are vectors

Multi-Systems ROF



Two (Fiber and Wireless) channels in series.
Two levels of modulation (optical and radio)
Multi system support
Ideally no signal processing at the ‘Radio Access Point (RAP)

Fi-Wi Systems also offer:

- Short air-interface - Low power transmission
- (Massive) MIMO capability
  - Multiple antennas with a good 'inter-distance' can be interconnected by fiber
- Wideband access
  - Low delay spread – less/no ISI (flat fading)
  - Frequent LOS path – less outage
- Coverage to special areas
  - tunnels, mines, super markets etc.
- Support mm-wave bands

$$Loss \propto 1/\lambda^2$$

Radio over Fiber

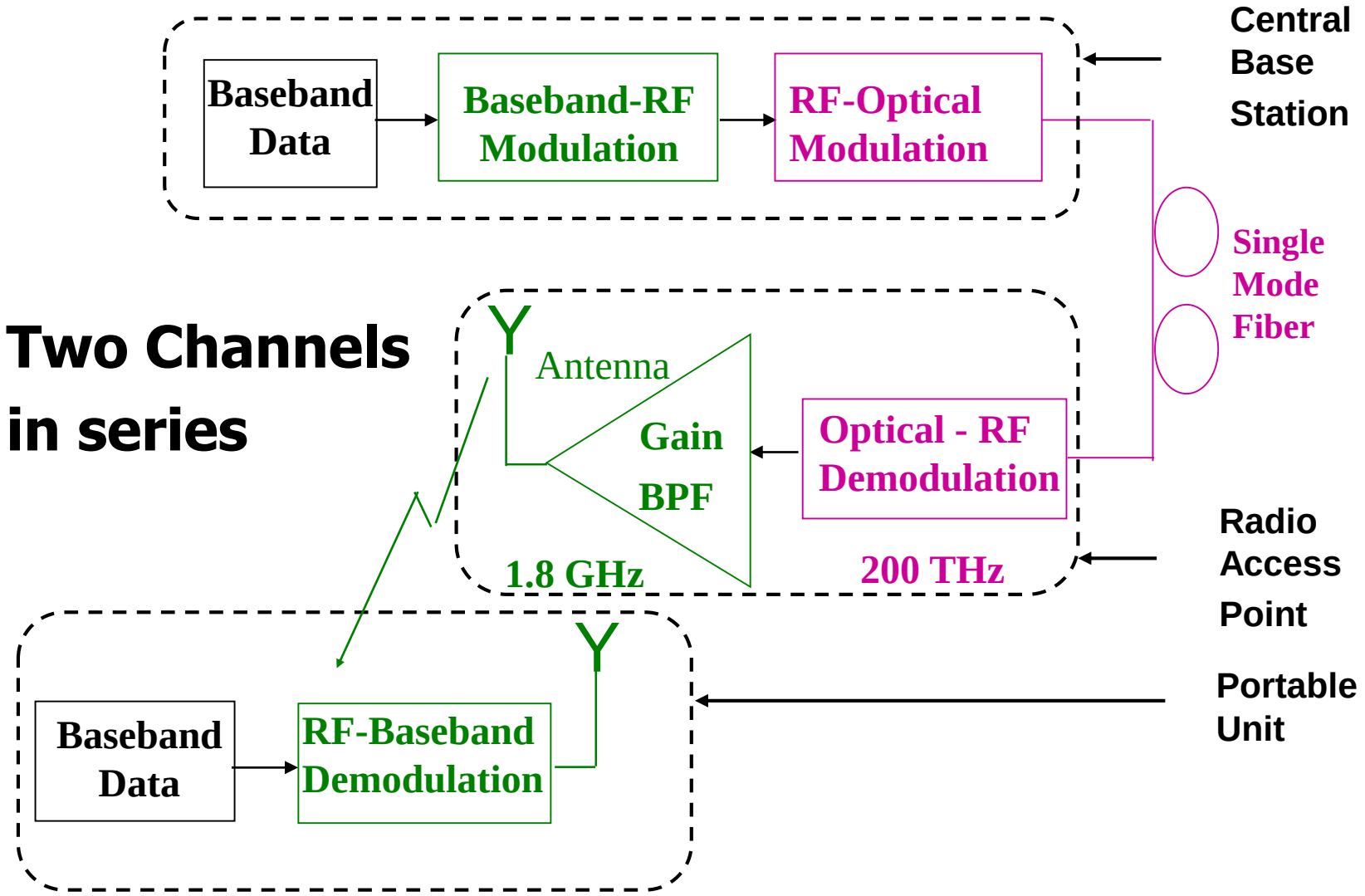
- All of the processing that enables internet traffic to turn into radio signals happens at a central station, so ROF is much cheaper to build, run and maintain than typical wireless distribution networks. It also means that new wireless standards – such as 5G wireless, and the latest Wi-Fi protocol, 802.11ac – can replace older standards simply by changing equipment at a central point - www.newscientist.com

ROF Deployment

"You could carry an entire town's wireless traffic over a single fibre-optic cable"
- Jeff Heynen, an analyst at Infonetics Research

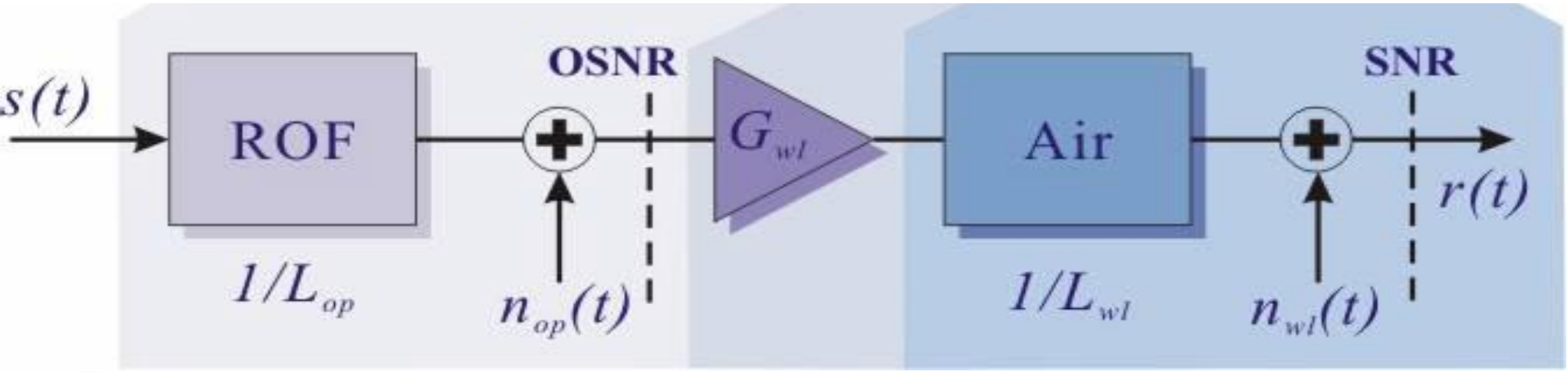
- China Telecom is building a 5G-oriented cloud radio access network (C-RAN) fronthaul network in the north-east Liaoning province using OTN and ROF – (http://www.telecomtv.com)
- As of 2016, telecoms giant AT&T had 4000 systems deployed around the US, boosting mobile broadband coverage in areas like stadiums and shopping malls using ROF.

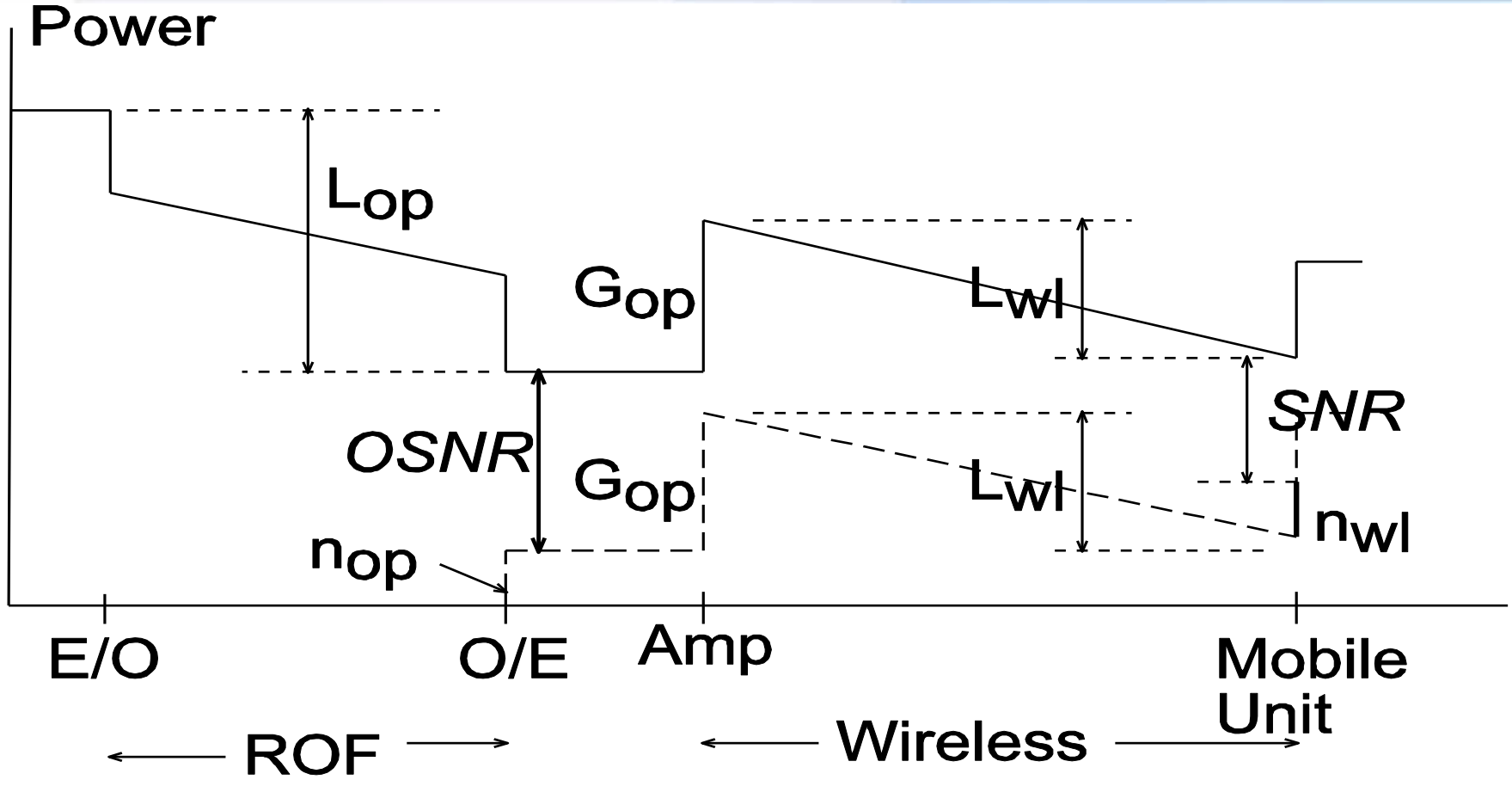
A Closer Look….



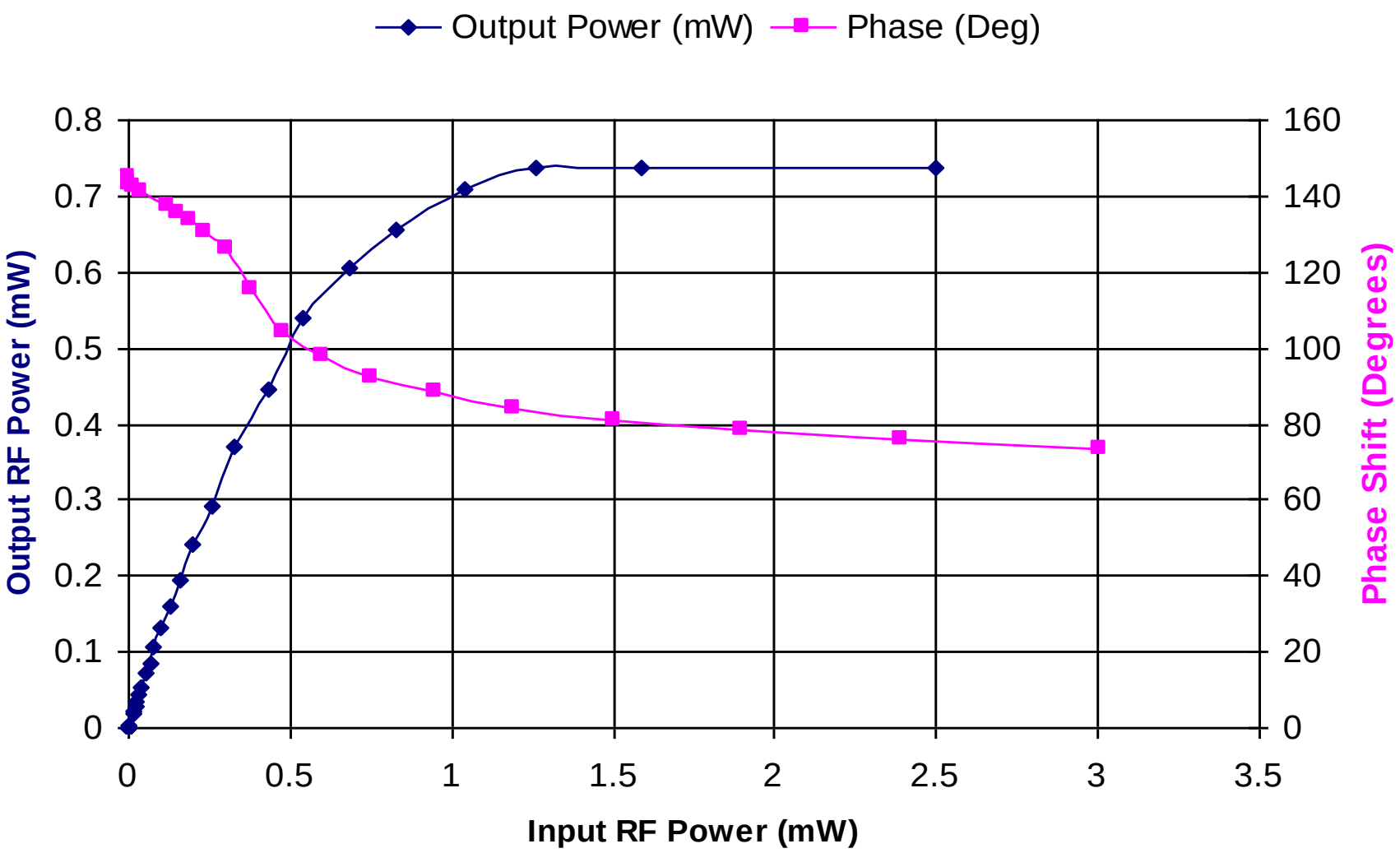
Research Directions

- Issue of two concatenated channels
  - The cumulative SNR is a weighted sum of optical and electrical SNR
- Optical link nonlinearity issues
  - Nonlinear, static optical channel is in series with time varying, dispersive wireless channel
- Microwave photonics
  - Optical generation, up/down conversion, (de)multiplexing of radio signals

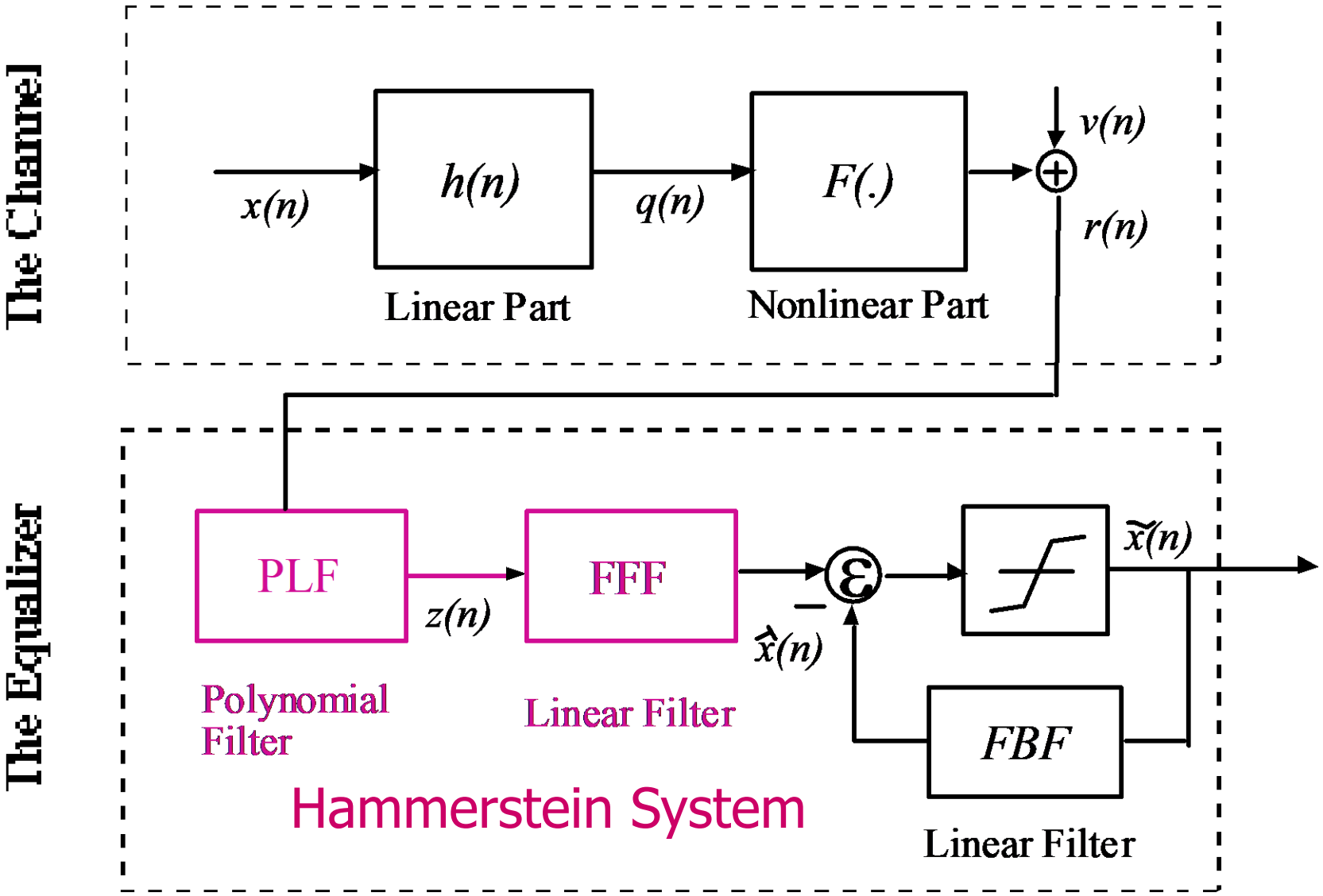

s(t)
ROF
OSNR
G_{wl}
Air
SNR
r(t)
$1/L_{op}$
$n_{op}(t)$
$1/L_{wl}$
$n_{wl}(t)$


Power
Lop
Gop
Lwl
SNR
OSNR
Gop
Lwl
nwl
nop
E/O
O/E
Amp
Mobile Unit
ROF
Wireless

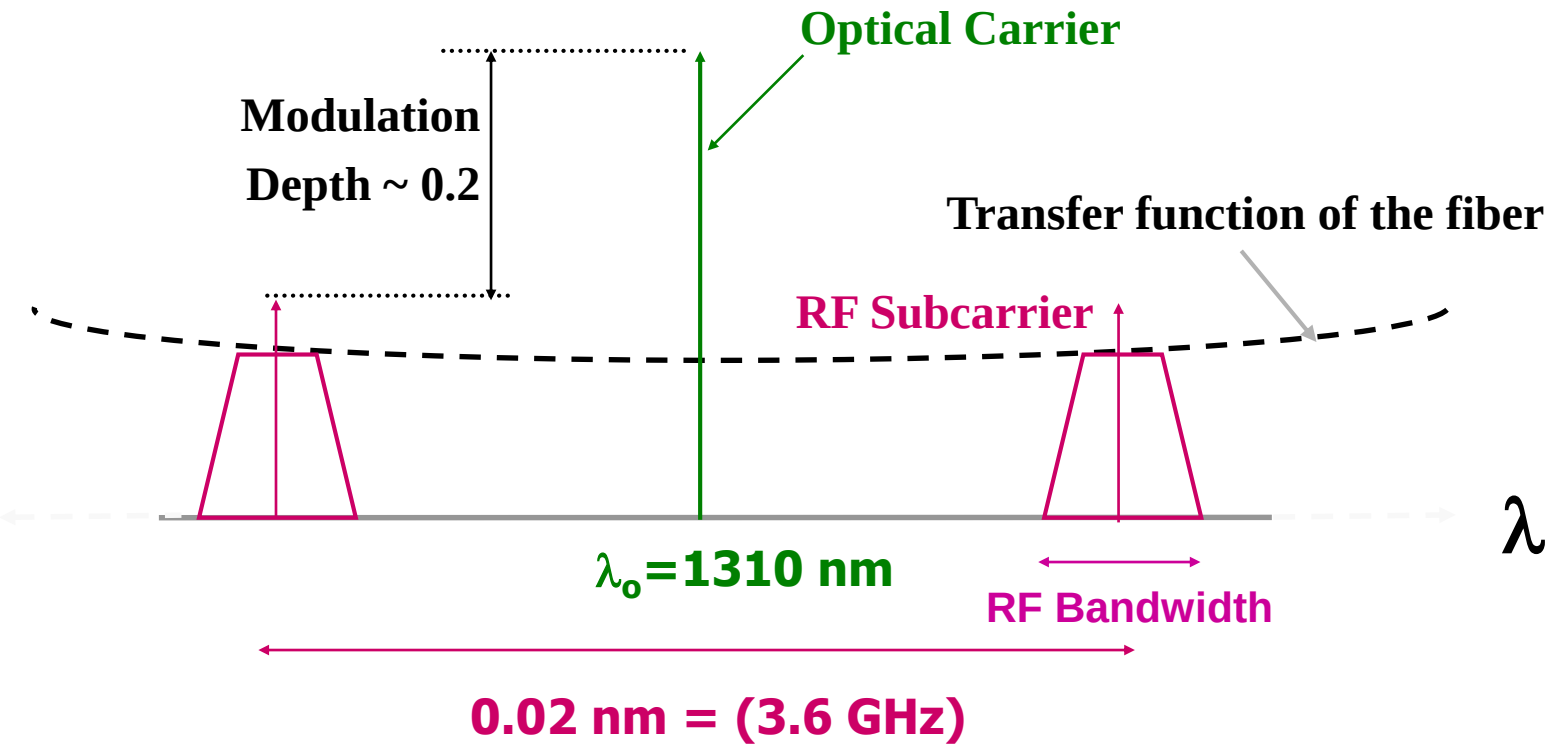
AM-AM & AM-PM Distortion



A Unified Compensation



RF Spectrum within the Fiber

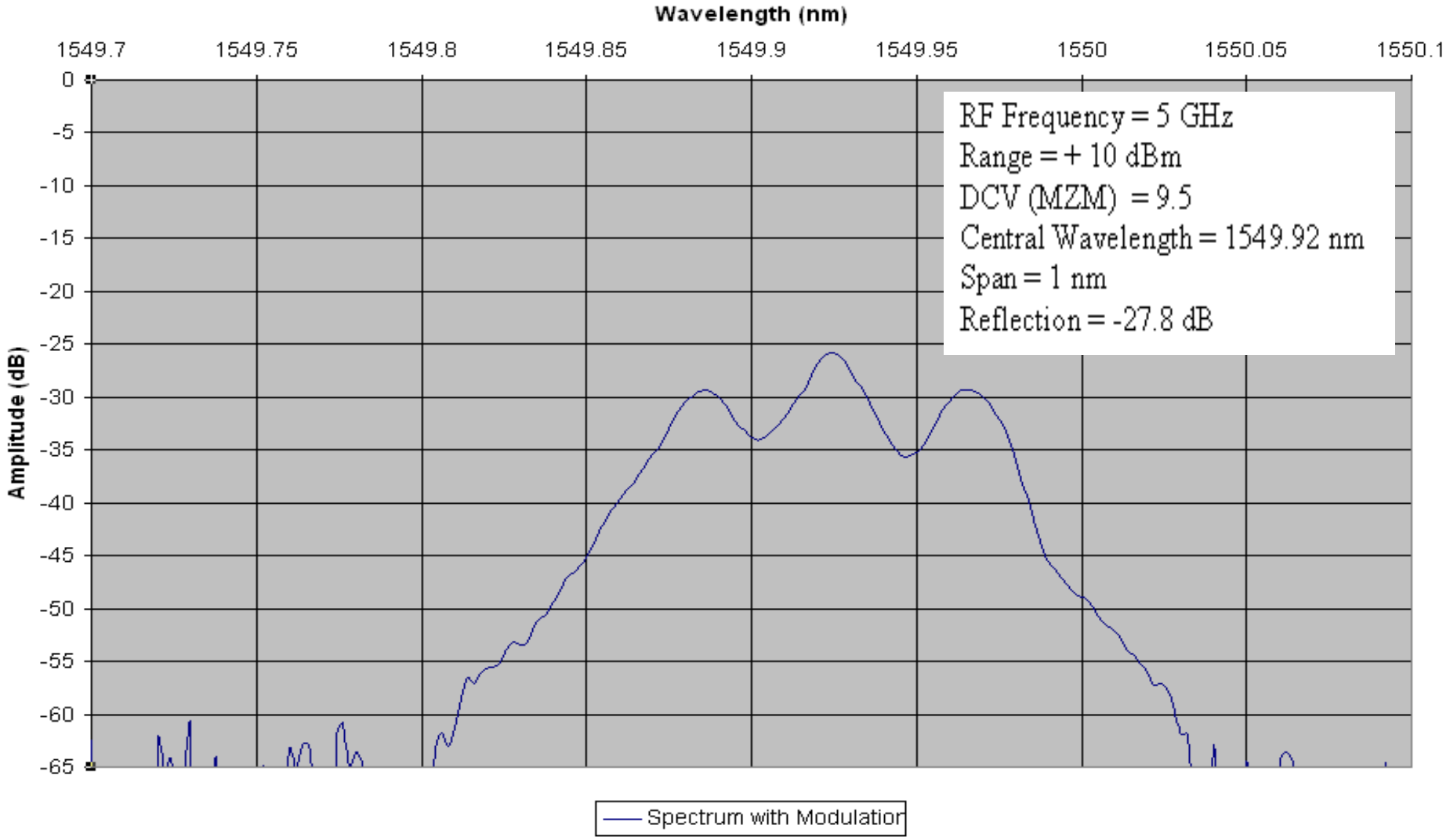


$$H(f) = exp[-j\alpha(\lambda)l(f-f_o)^2];$$

l: length, α*:*Dispersion factor

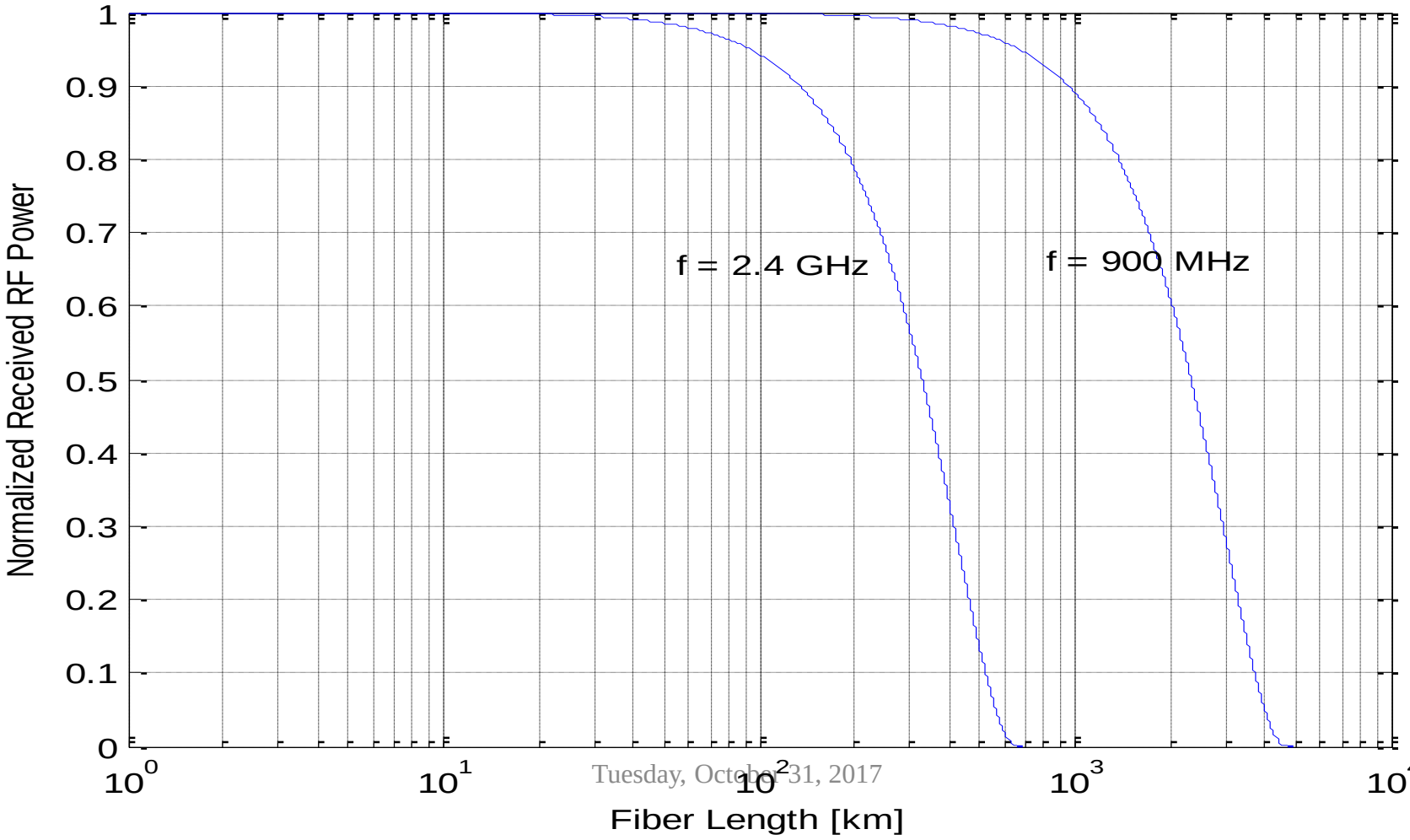
Fiber dispersion will rotate the phase of sidebands

Spectrum with 5 GHz RF Sidebands

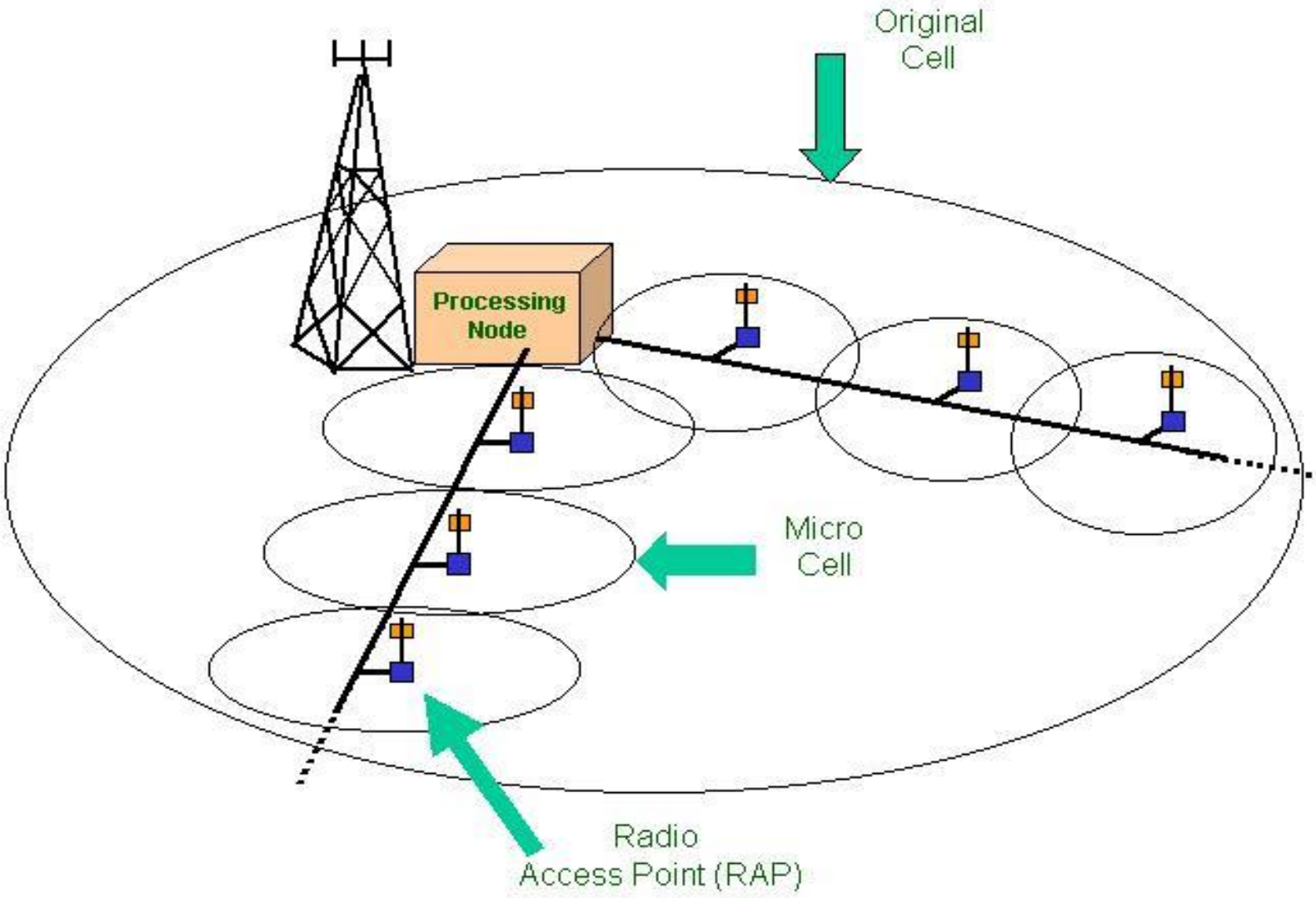


Fiber Chromatic Dispersion

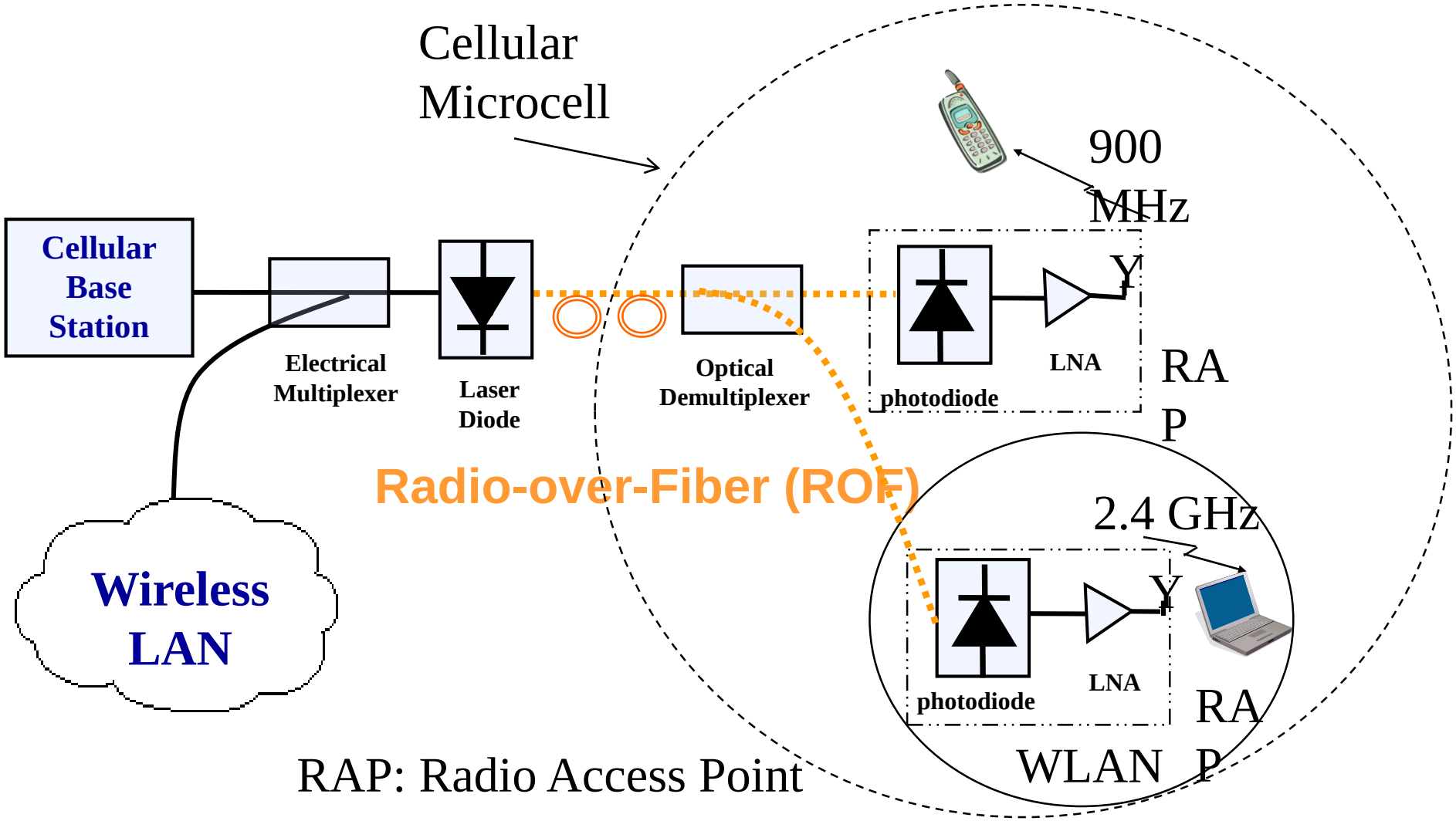
Dispersion can cause 180º between the USB and LSB and lead to sideband cancellation – This is not a concern up to few GHz



More Practical ROF Bus Network



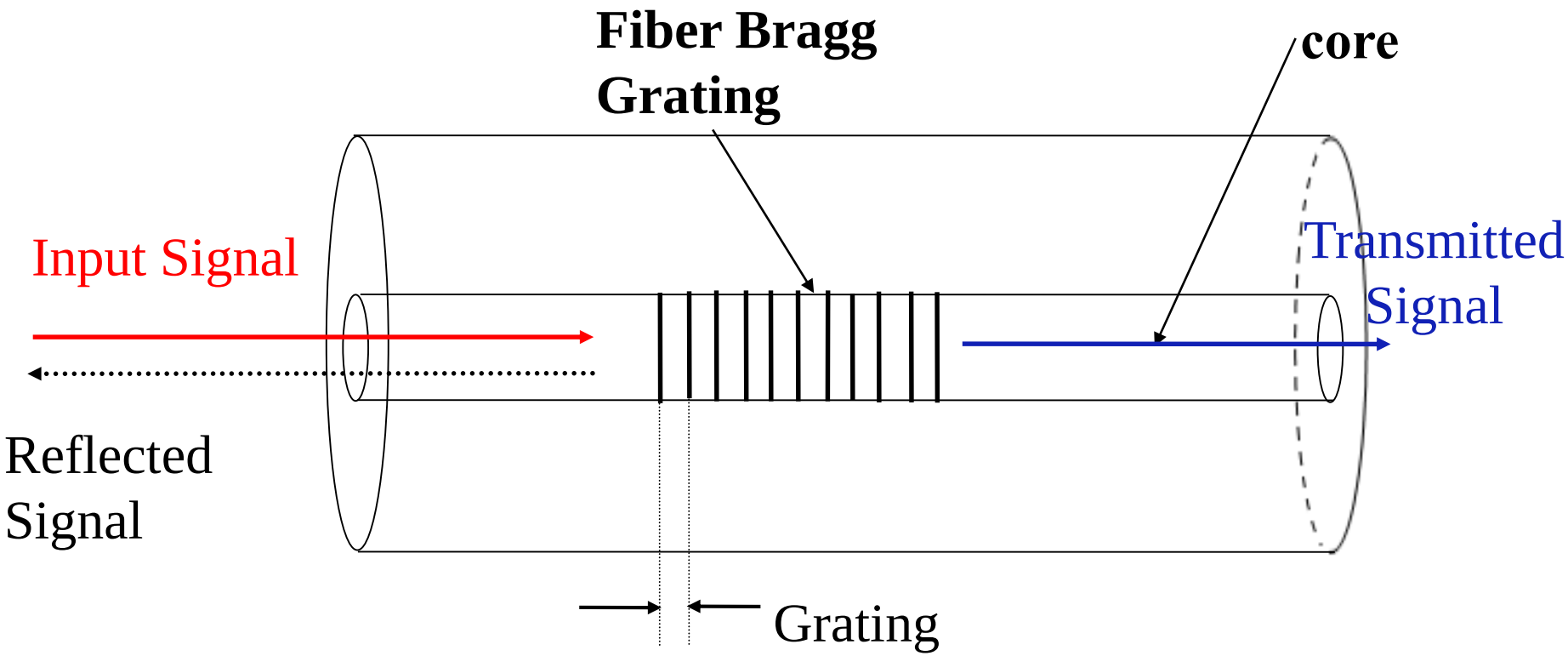
All-Optical Demultiplexing



All-Optical Demultiplexing

- Any RF subcarrier can be accessed at any point in the ROF network.
- Unnecessary loss, noise and distortion due to O/E and E/O conversion are avoided.
- The photodetector can have low bandwidth (matched to only one subcarrier)
- Significant cost reduction
- Works well with PON access network architecture

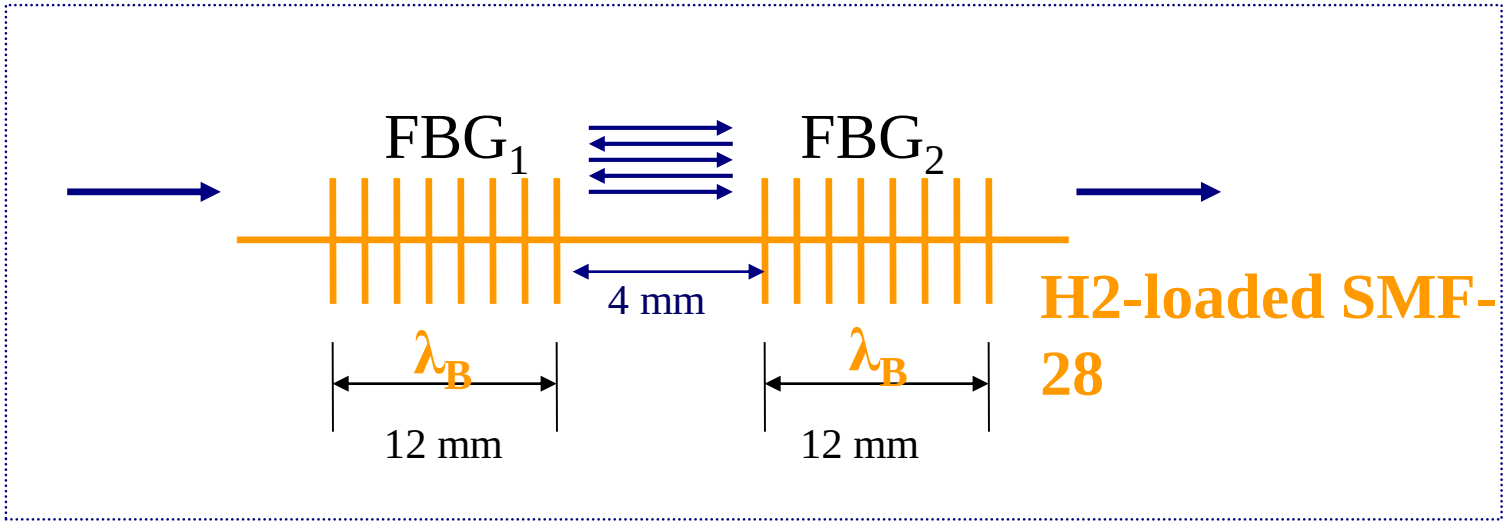
Grating Structure in the Fiber Core



$$\lambda_{Bragg} = 2\Lambda n_{eff}$$

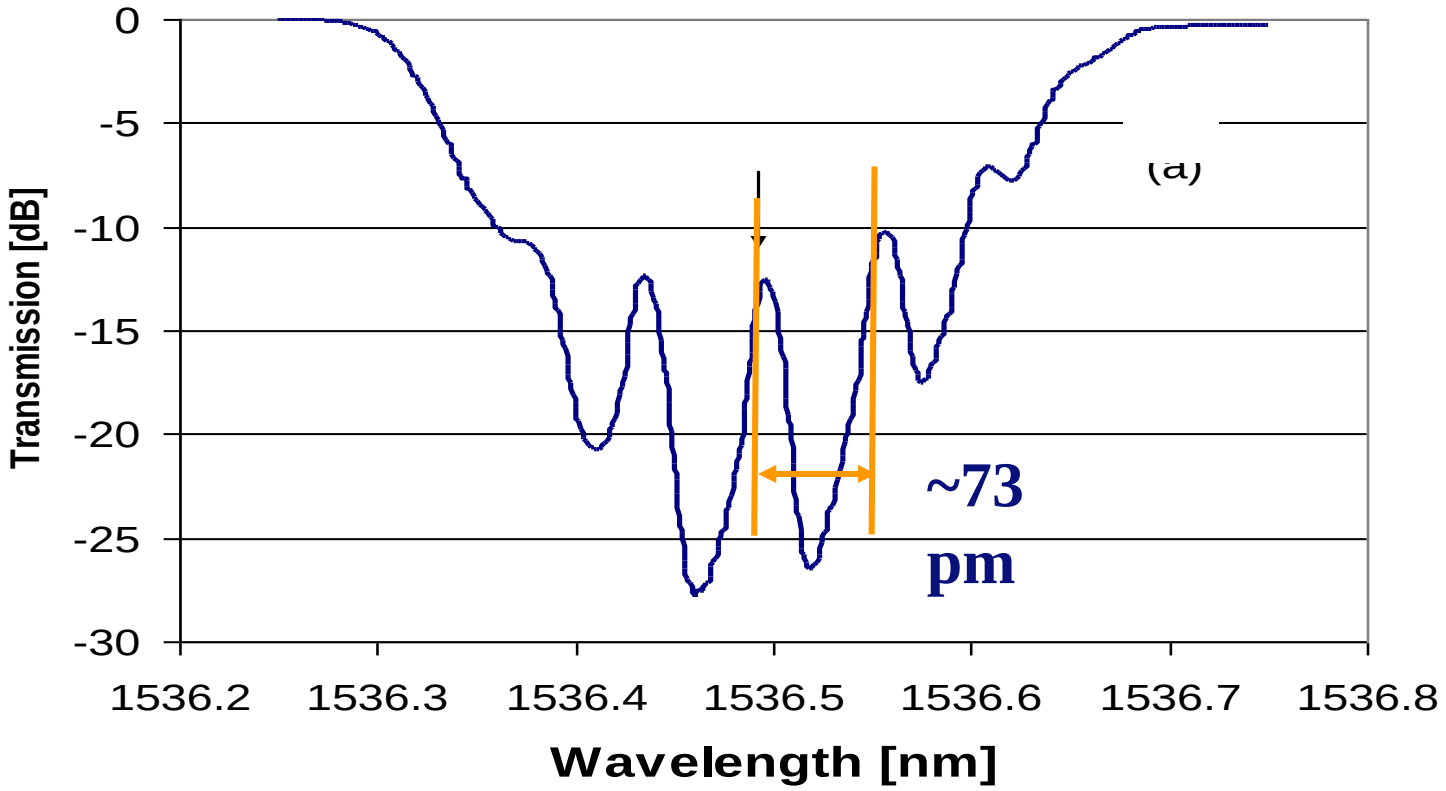
FBG-Based Resonance Filter

- A highly reflective filter with a bandwidth in the sub-Pico meter range was imprinted using two highly reflective FBGs, which formed a resonator
- The overall length of the filter is 28mm



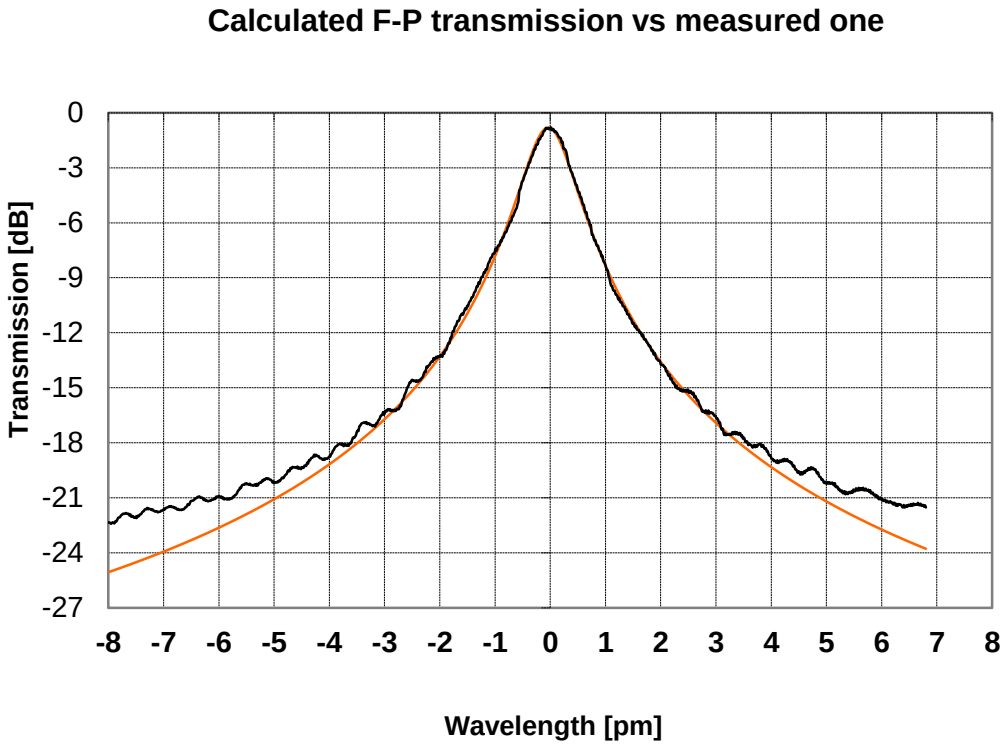
Transmission Spectra of the Resonance Filter

- The stop bandwidth of the FBG was ~ 0.3 nm at -3 dB and five resonant peaks were created.
- The bandwidth of the resonant peak is determined by the length of the resonator and the reflectivity of the FBG.



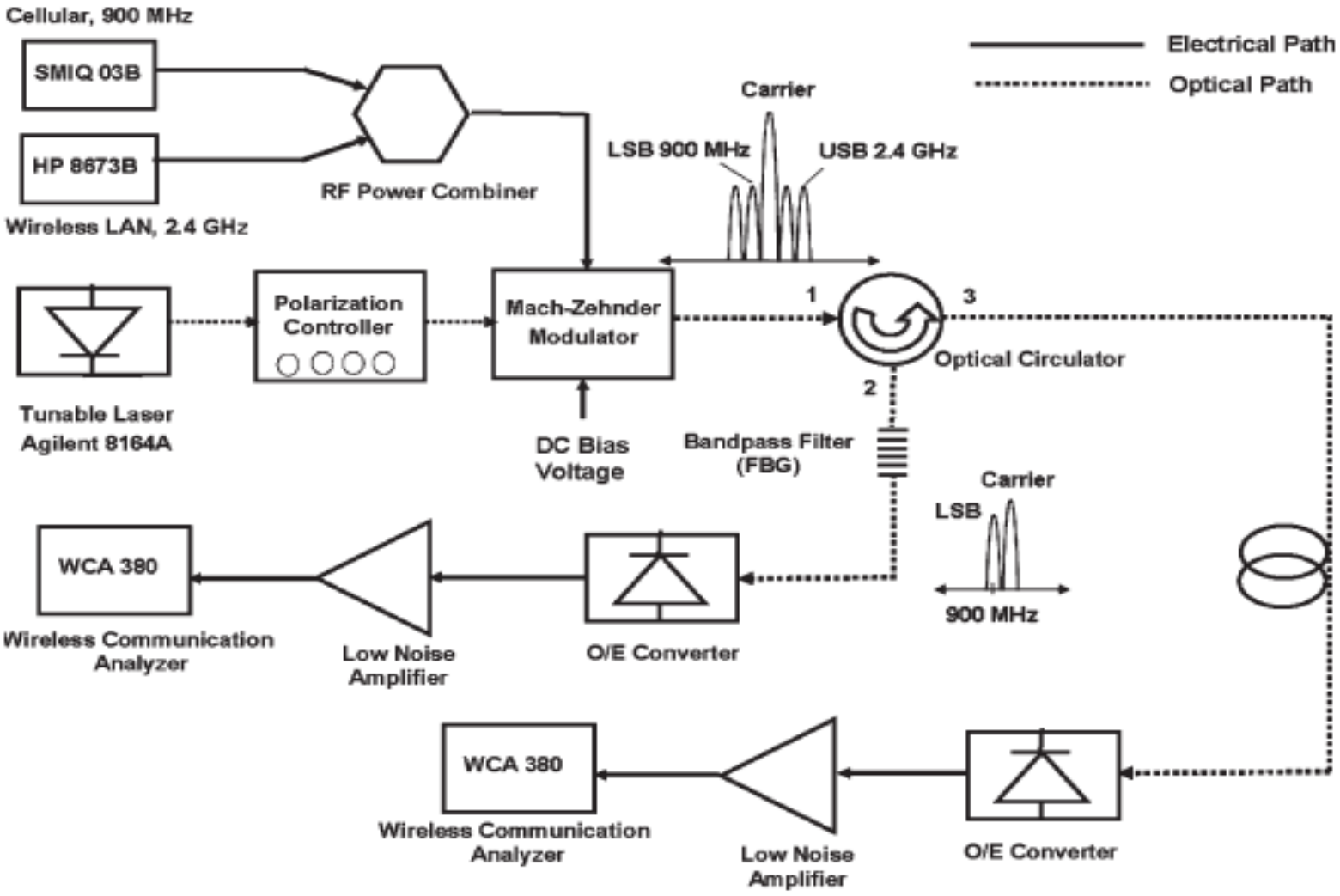
Filter Transfer Function

The spectrum of resonant peak (black trace) was obtained by scanning the sideband over a 2 GHz range at 4 MHz per step. The red trace was the calculate[illegible] planer Fabry-Perot resonator.

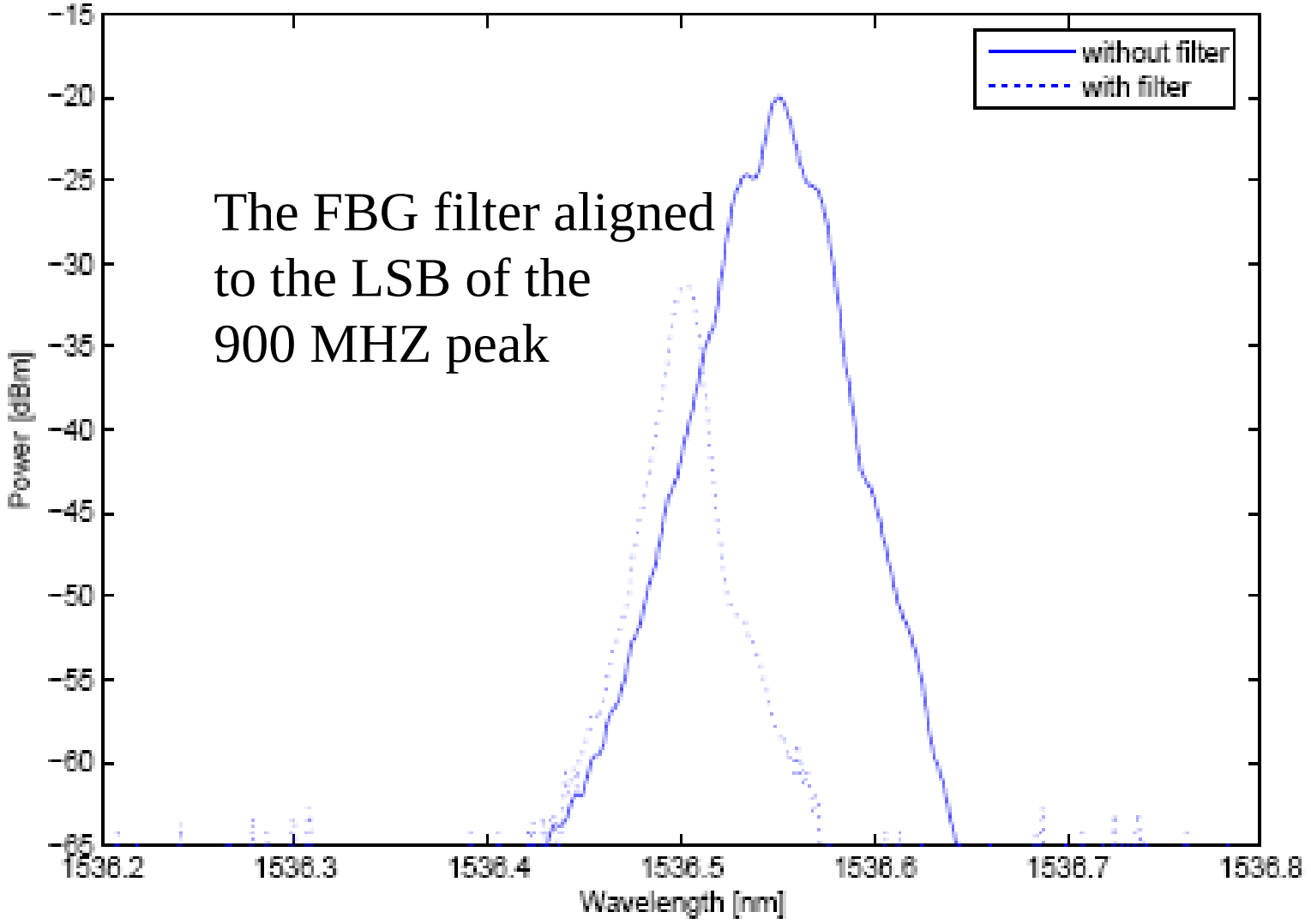


- The filter has a bandwidth of
  - 120 MHz at -3 dB
  - 360 MHz at -10 dB
  - 1.5GHz at -20 dB
- The insertion loss is 0.8 dB at the resonant peak.
- Filter is polarization sensitive

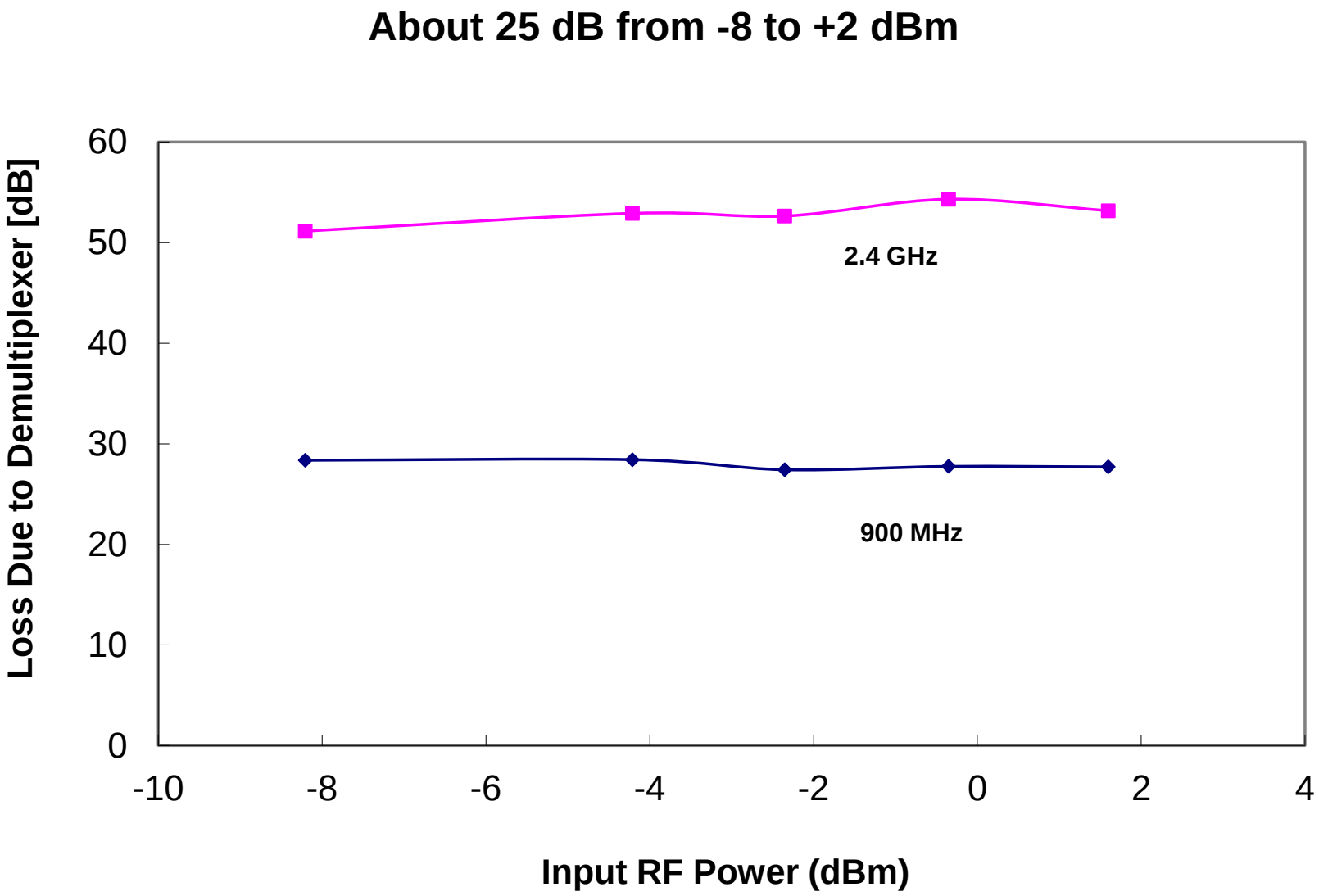
Demux Experiment



Filtered Spectrum

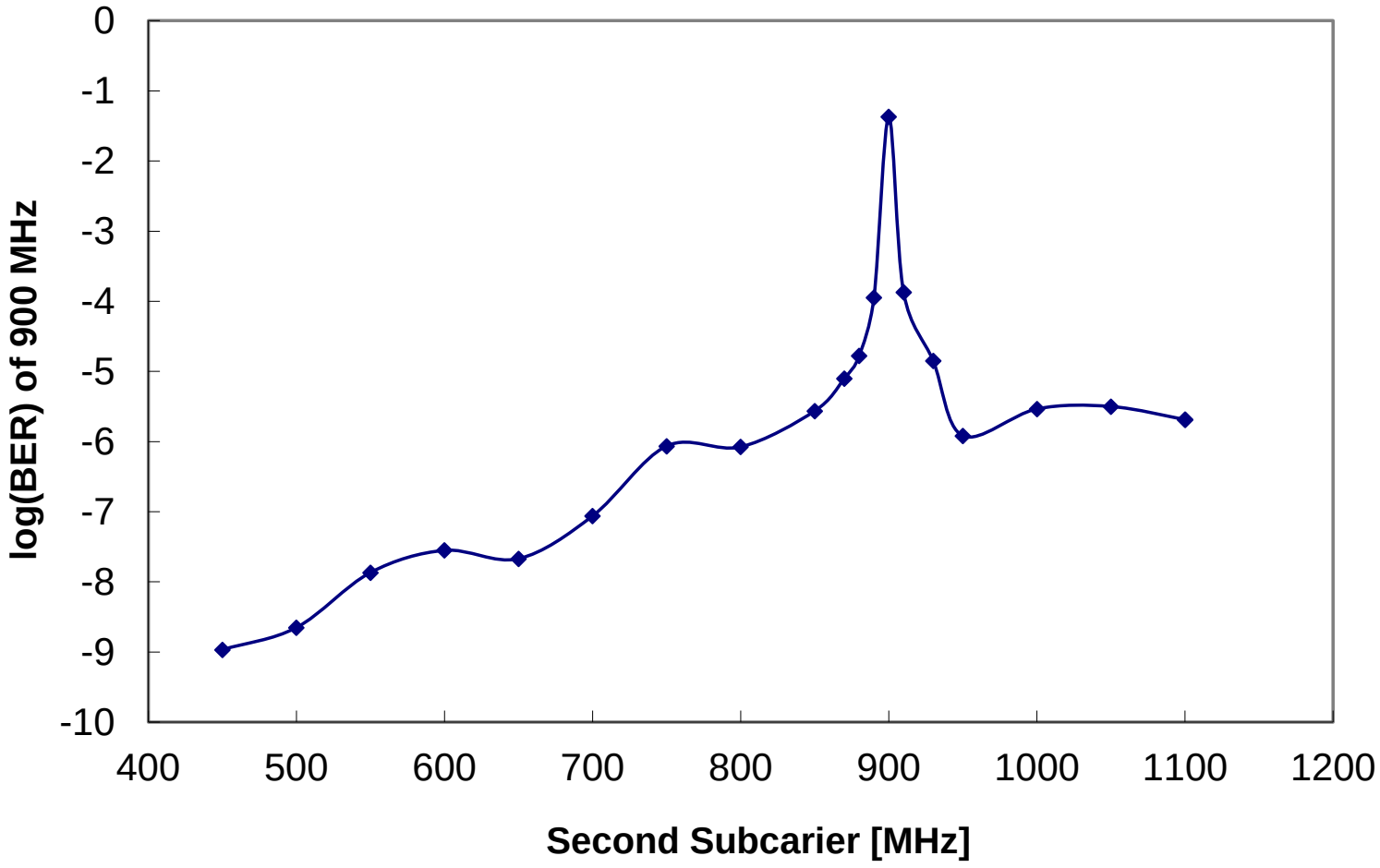


Selectivity of the Demultiplexer

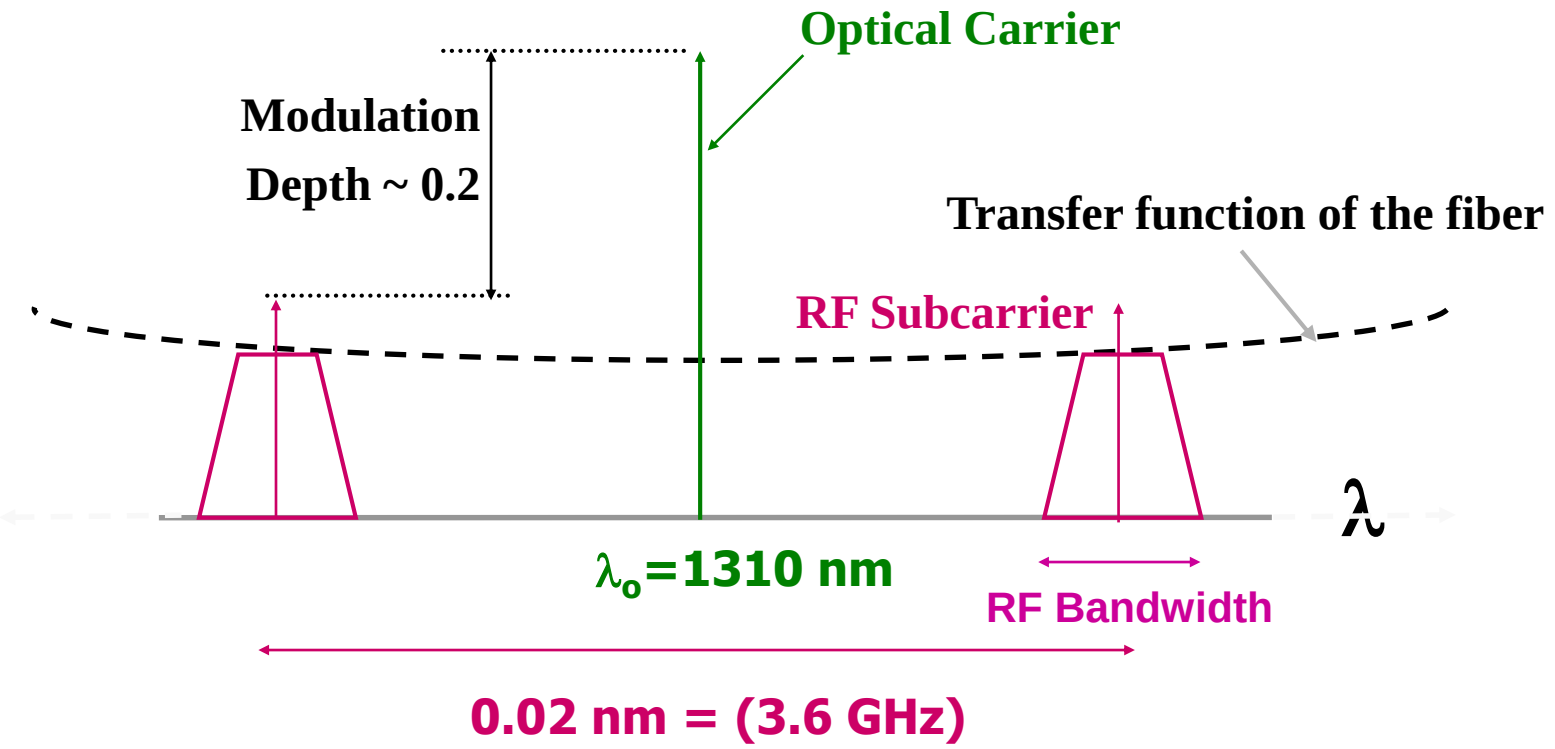


Frequency Separation of the Filter

- The BER performance of 900 MHz signal at the filter output as the 2nd subcarrier was swept from 450 MHz to 1.1 GHz
- The BER level at 50 MHz separation is 2.72×10^{-6}



Modulation Depth

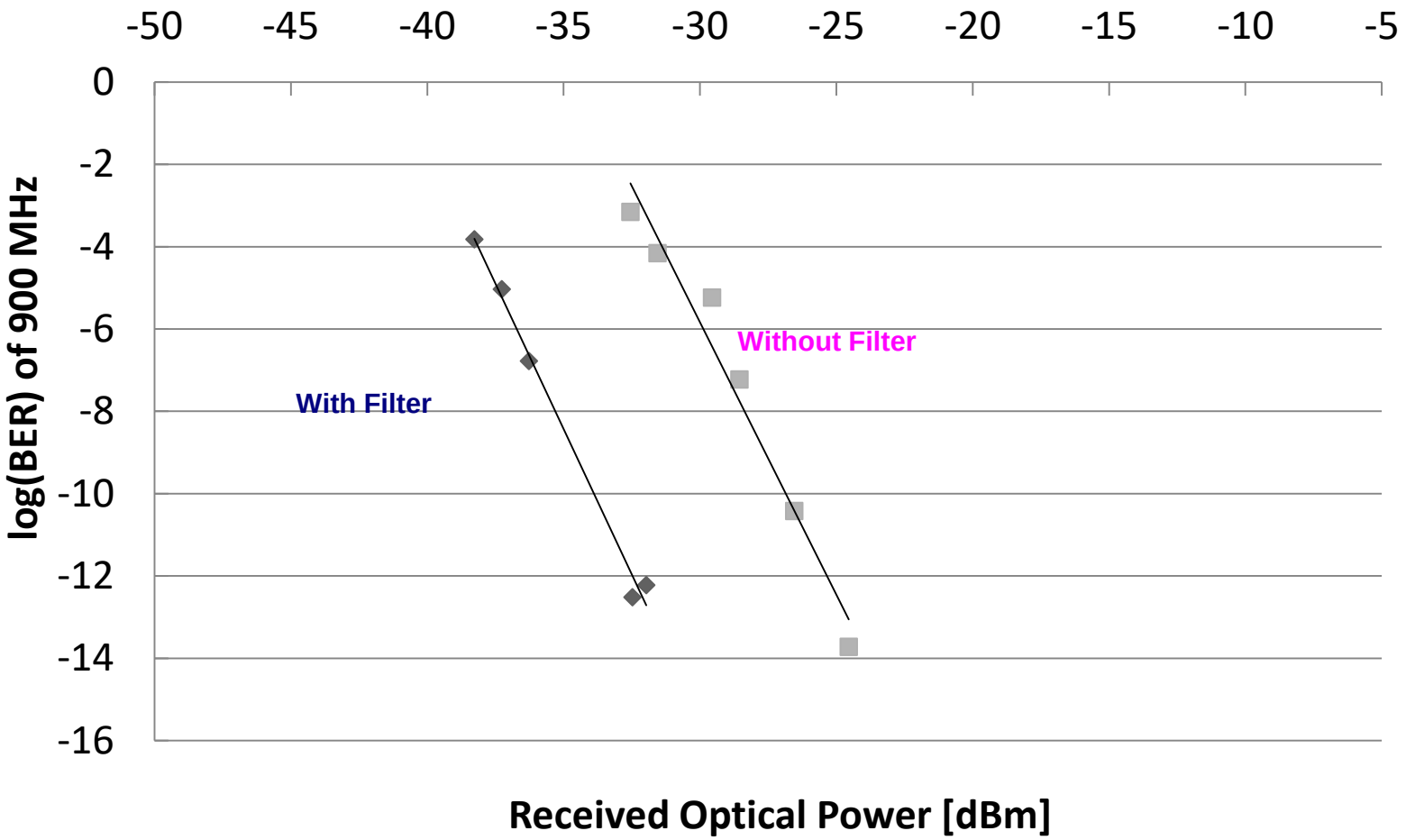


- Modulation depth normally kept low to avoid extensive nonlinear distortion
- Carrier does not carry useful information, just floods the photodetector

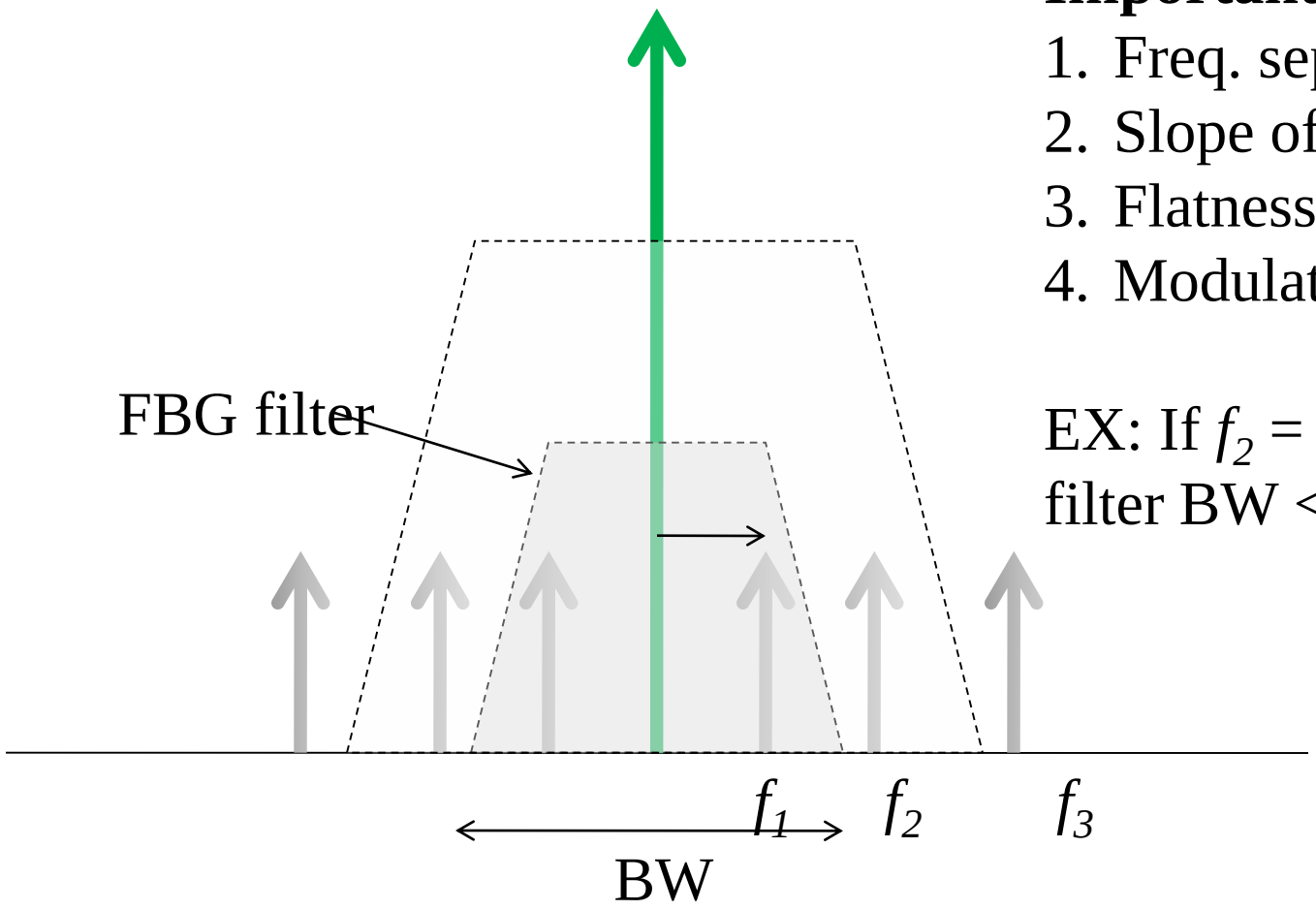
Carrier Suppression

Narrow optical filters can be used to suppress un-modulated carrier

In this case sensitivity improvement ~7 dB



Single FBG based SCM Demux

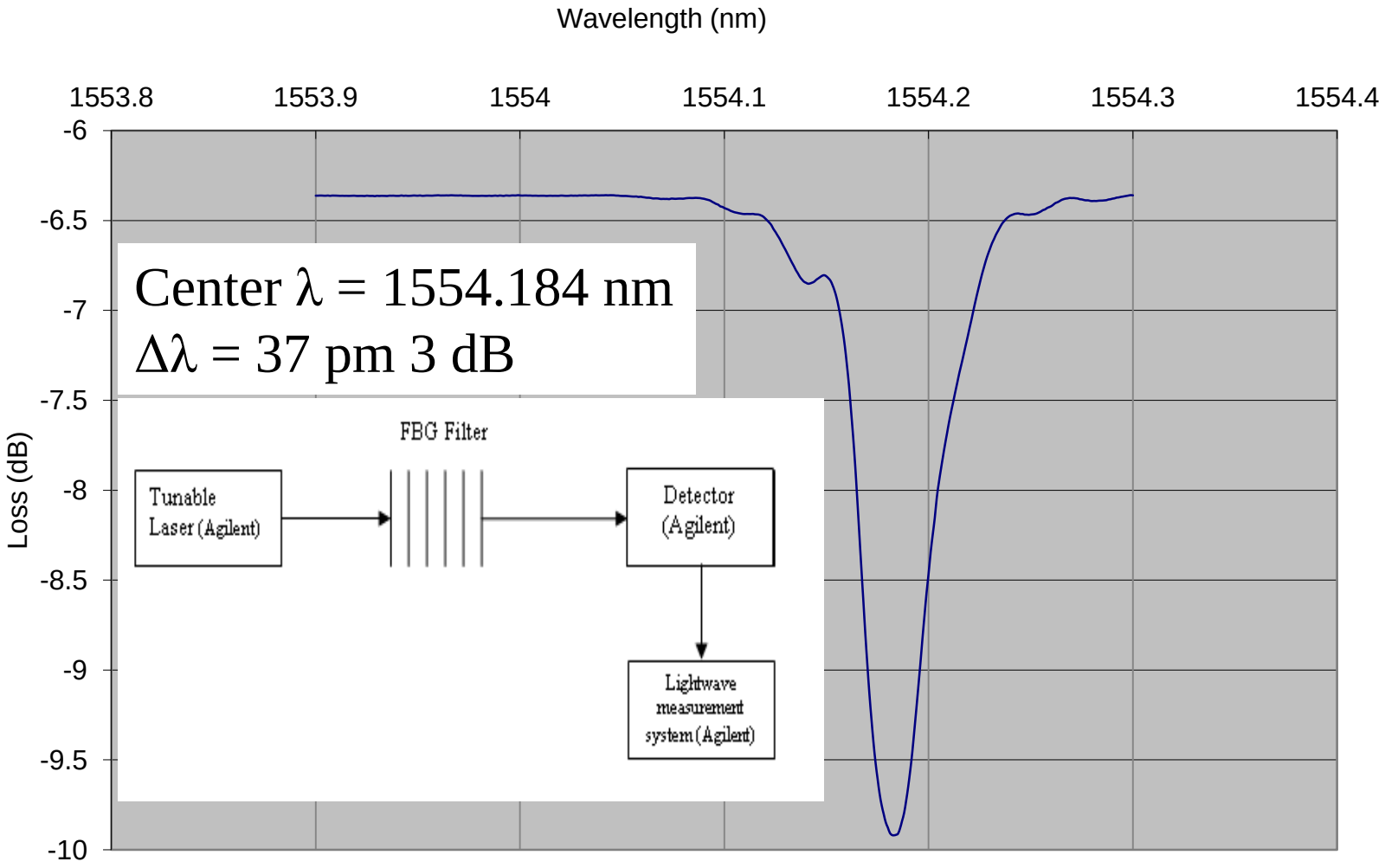


Important Parameters:

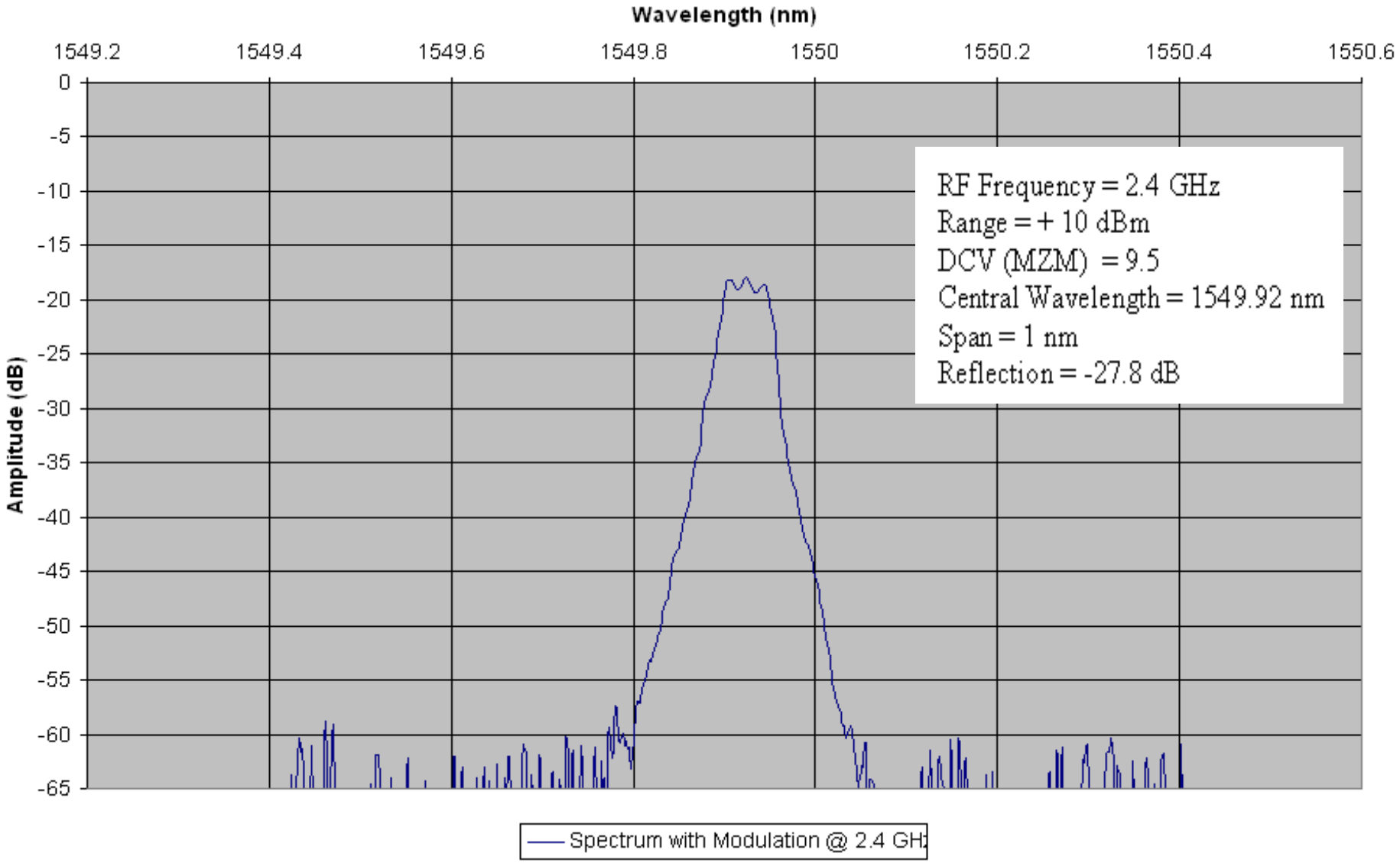
1. Freq. separation (f_i - f_j)
2. Slope of the FBG filter
3. Flatness of the filter top
4. Modulation depth

EX: If f_2 = 2.4 GHz,
filter BW < 38.6 pm

Transmission Characteristics of an FBG Measured by Agilent 8164A



Spectrum with 2.4 GHz RF Signal



Conclusions

- Radio over Fiber is an attractive approach for wideband wireless access
- Fiber has ample bandwidth
- Lots of existing dim/dark fiber
- Supporting multiple standards is possible
- Major concerns are
  - High loss and noise due to concatenated channels
  - Nonlinear distortion and limited dynamic range of the ROF link
- Some emerging areas like coherent modulation will improve the situation