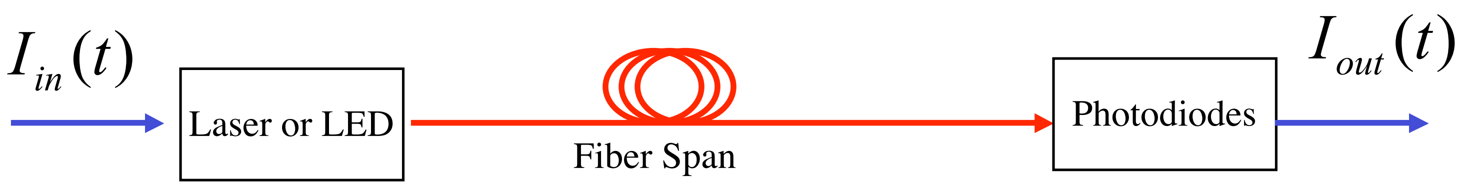
Lecture 13

Hybrid Networks

- The fiber optic transmission medium offers an extremely high bandwidth pipe that can be merged with other non-optical physical layer technologies to realize cost and performance benefits.
- Optics may provide platforms to mix analog and digital modulation techniques
- This approach is often used in access networks
- We will briefly outline these applications
  - We start by reviewing several mixed analog-digital transmission on a fiber based on subcarrier modulation
  - Then, we present some applications
    - Antenna Remoting
    - Fiber to the X

Fiber Analog Transmission

- So far, we have only discussed digital transmission on fibers
- Still, analog transmission is possible, and it is often used in short haul applications, like in access in the metro area
- The principle is the following



- In this scheme, $I_{out}(t)$ is, to a first approximation, directly proportional to $I_{in}(t)$
- Thus, at least in principle, a high bandwidth linear link between transmitter and receiver is available

Analog Transmission: Fiber vs. Cable

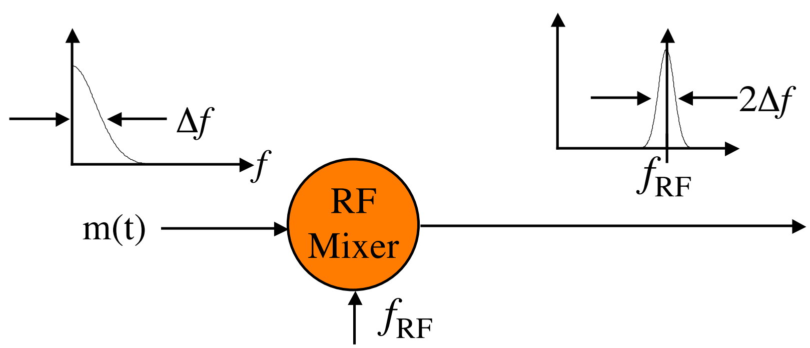
- Fiber has a much higher bandwidth and smaller attenuation than any kind of electrical cable
- The disadvantages are mainly related to the optical link nonlinearities due to:
  - The fiber, if high power is launched at the input
  - The Laser (or LED) due to clipping effects or non-idealities in the PI transfer function
  - The external modulator (when used) due to its intrinsic non linear (cos^2) transfer function
- In high performance analog application, a suitable pre-distortion circuit is required at the transmitter

Standard (Electric) Analog Modulations

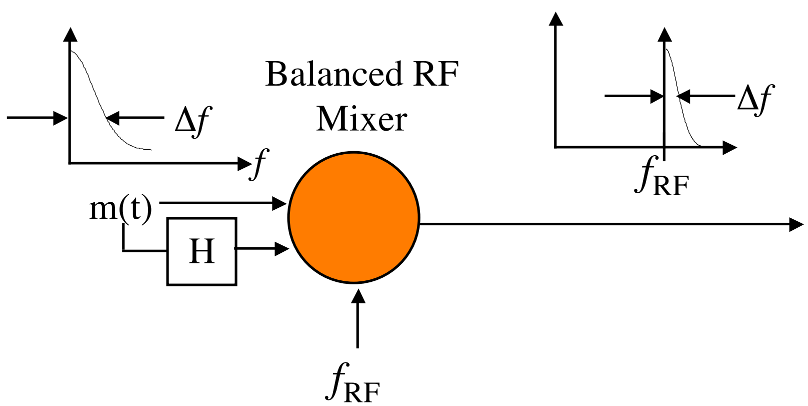
- The typical (electrical) Amplitude Modulations (AM) are briefly reviewed in this slide

In general, an analog information signal *m(t)* at baseband is encoded on an (electrical) frequency f_{RF}

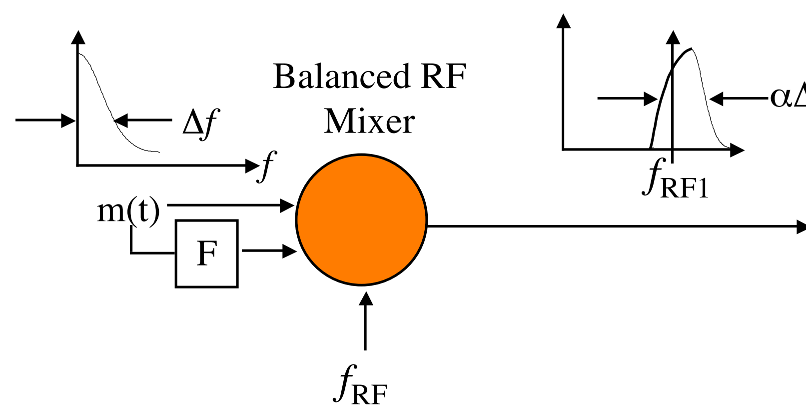
Double Sideband (DSB) Modulation



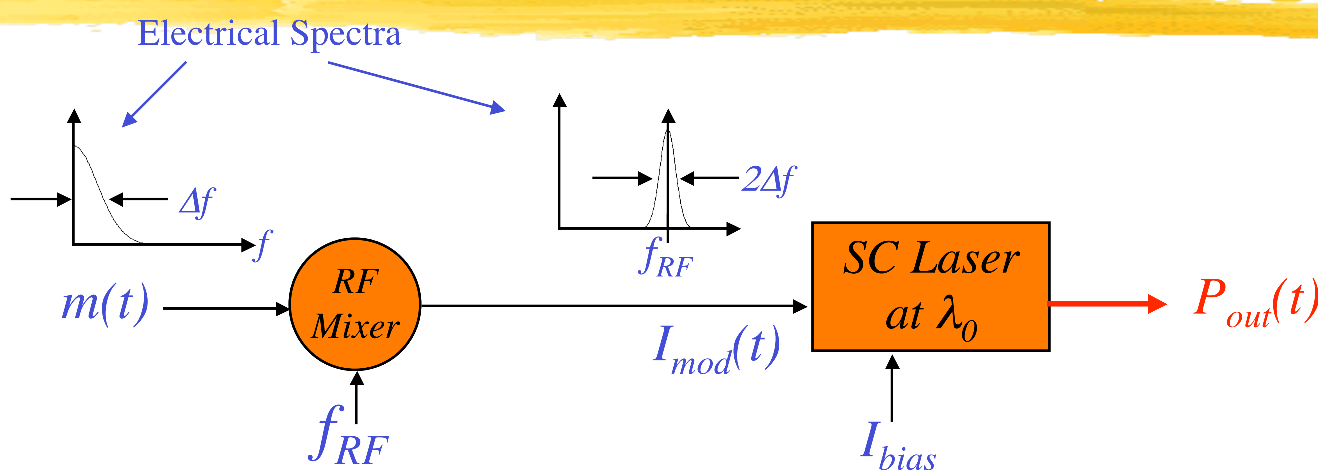
Single Sideband (SSB) Modulation



Vestigial Sideband (VSB) Modulation

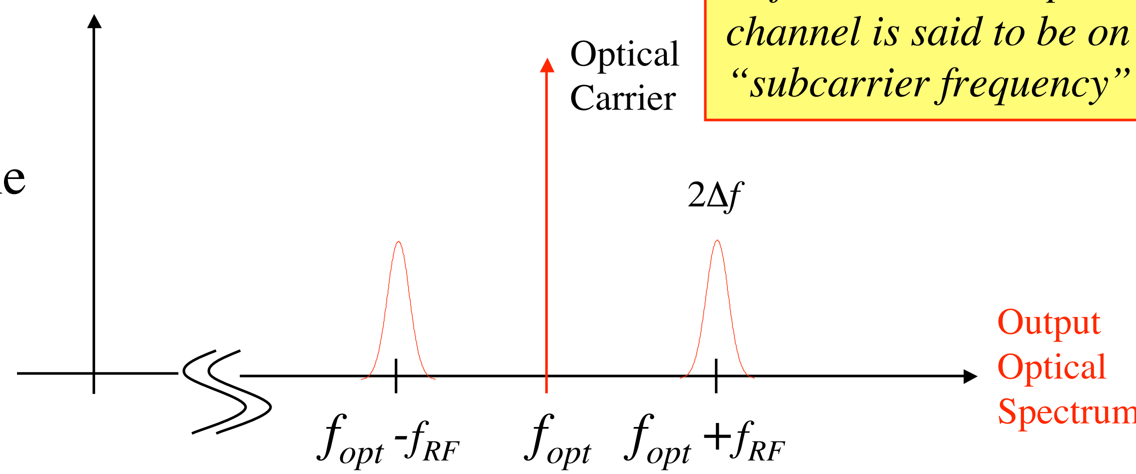


Optical Subcarrier Multiplexing



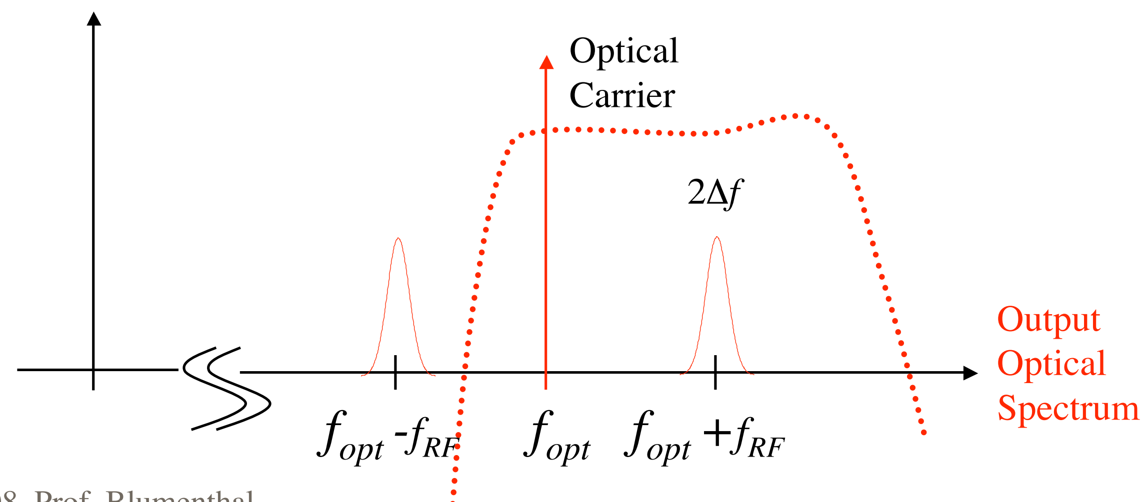
Definition: in the optical domain, the channel is said to be on a "subcarrier frequency"

f_{opt} is the optical frequency corresponding to the wavelength λ_0



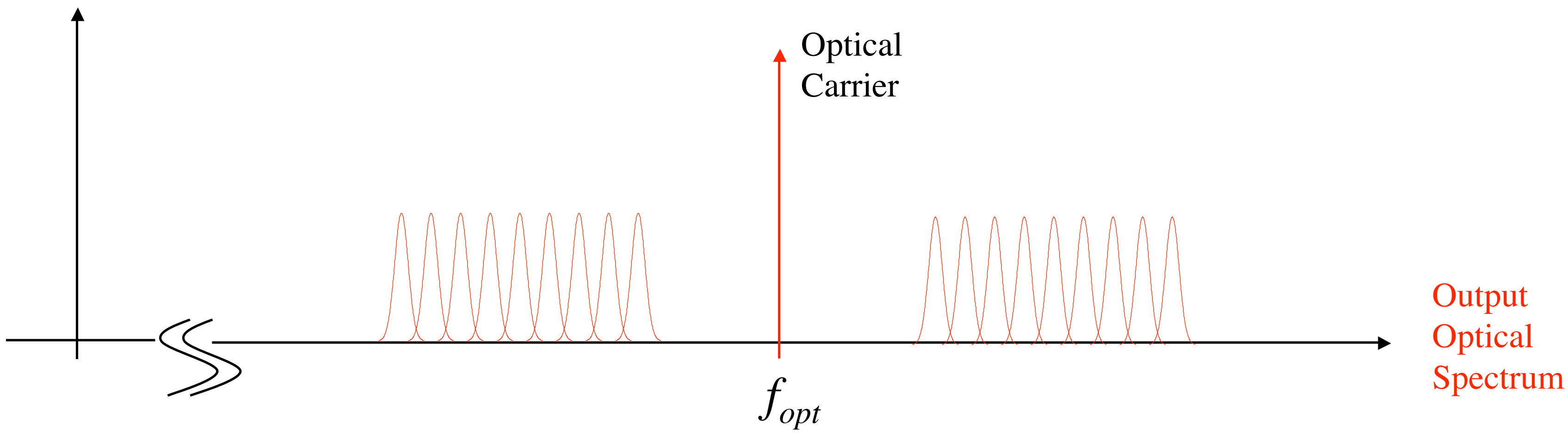
Subcarrier Multiplexing and Dispersion

- In the previous example, the signal has a bandwidth $2\Delta f$ but it is replicated on both sides of the optical carrier, at a distance f_{RF}
- In terms of dispersion, the two sidebands see opposite phase shifts due to dispersion
  - Thus, fiber dispersion effects are related to f_{RF}, and not to the actual much smaller information bandwidth Δf
  - Example: TV signal with a 5 MHz information bandwidth and 450 MHz carrier frequency. Dispersion is related to the 450x2= 900 MHz bandwidth
- Single sideband optical modulation format have been proposed to highly reduce dispersion effects (at the cost of a much higher complexity)



Optical Subcarrier Multiplexing

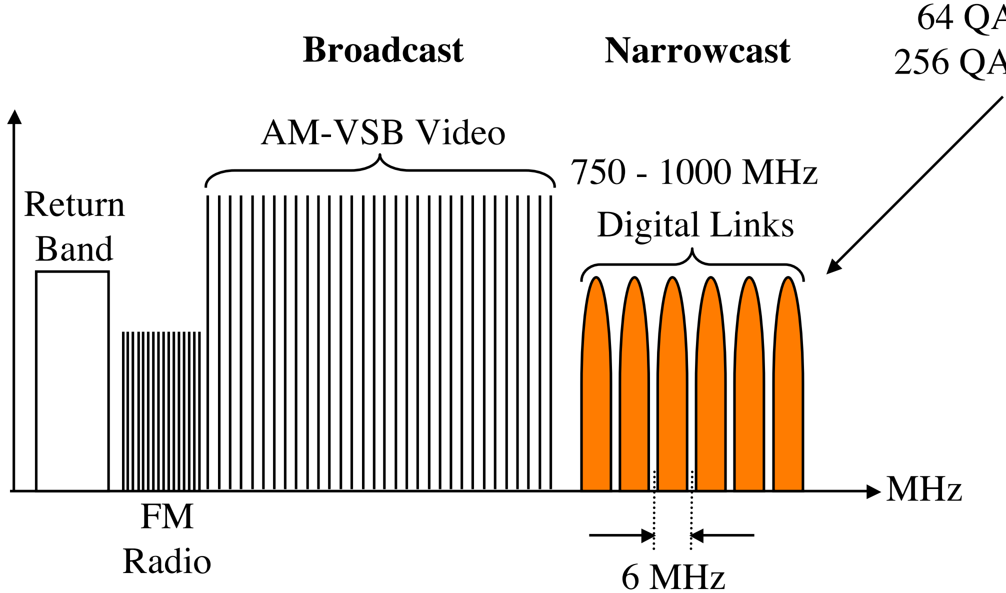
- When several AM modulated electrical channels are sent to the same laser, the resulting optical spectrum is as follows
- This is a standard approach for multiplexing several channels (analog or digital) on the *same* optical carrier (single laser at a given wavelength)



Hybrid Fiber/Coax Spectrum

- The information to be carried along the link has a quite complex spectrum
  - Several relatively low bandwidth or bit rate signals are carried to the final user
  - Some signals may be analog, others digital
- Typical frequency Division Multiplexing FDM, similar to what it is used in radio links, is used

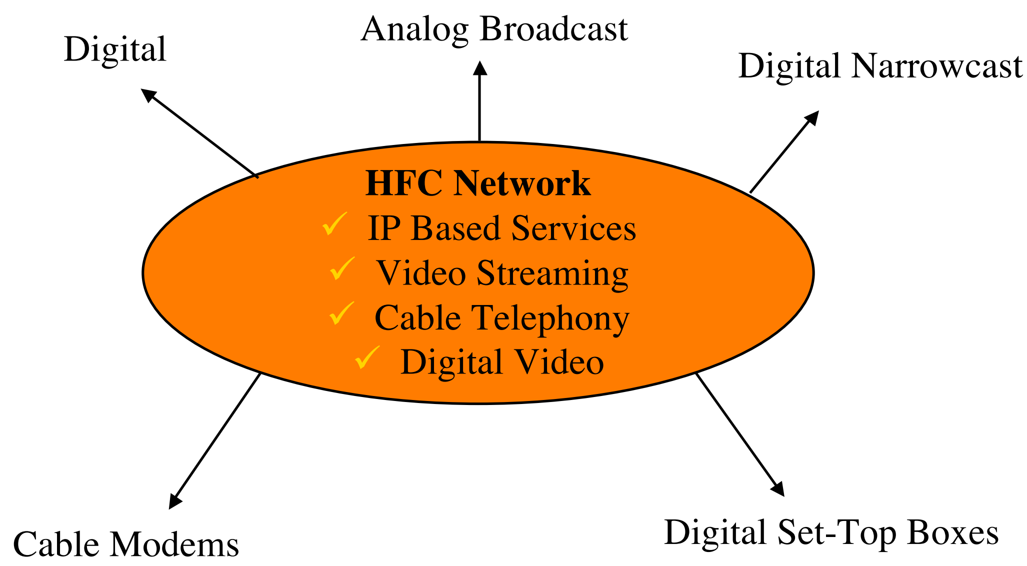
64 QAM: 30 Mbps channel, 26 Mbps data
256 QAM: 43 Mbps channel, 36.5 Mbps data

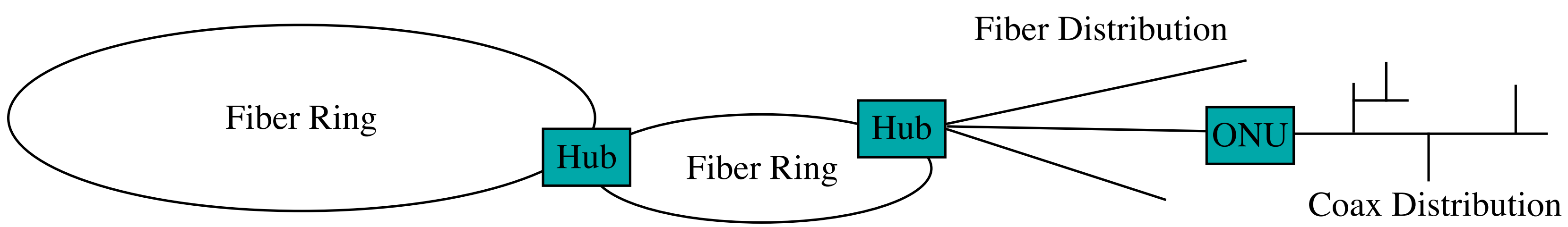


Cable Modem Standards
31.6 Mbps, 6 MHz
41.3 Mbps, 8 MHz

Definition: the central frequency of each of the channels is called “carrier frequency” in the electronic domain

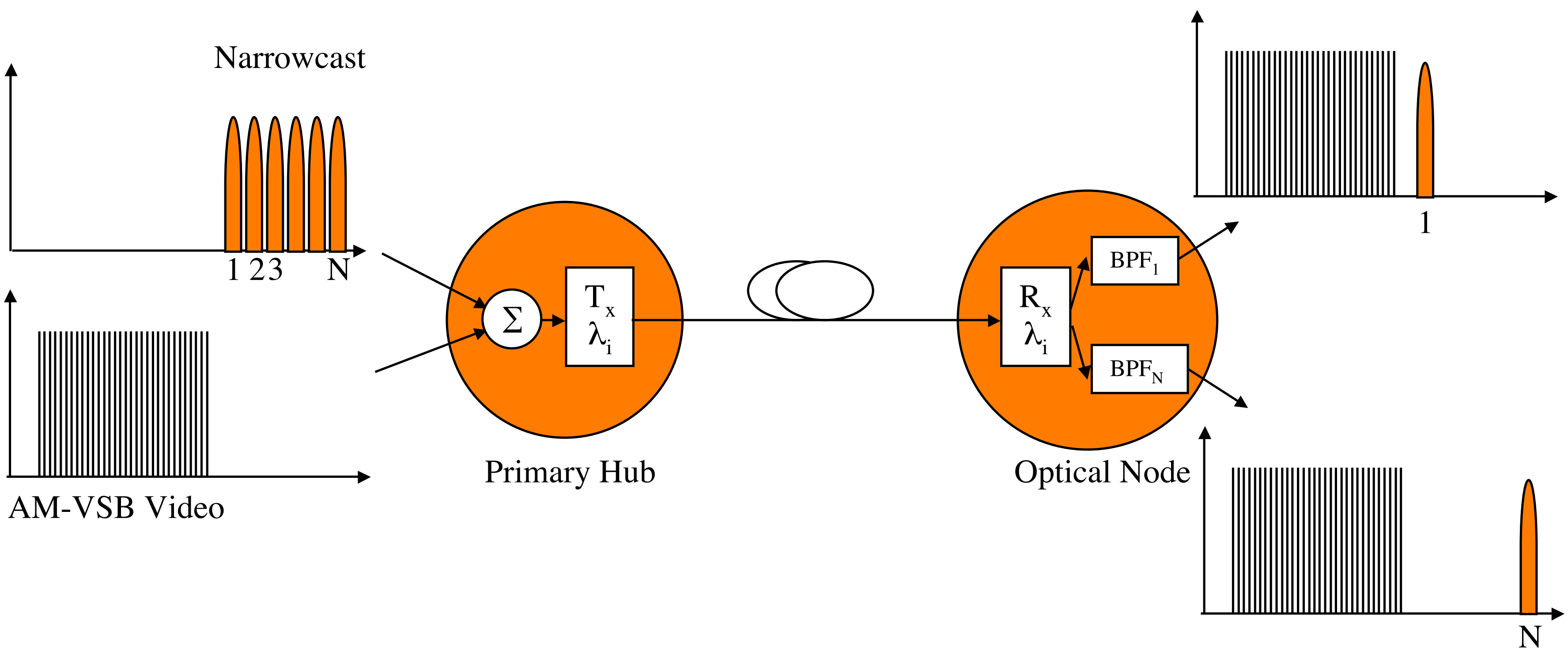
Hybrid Fiber/Coax Networks





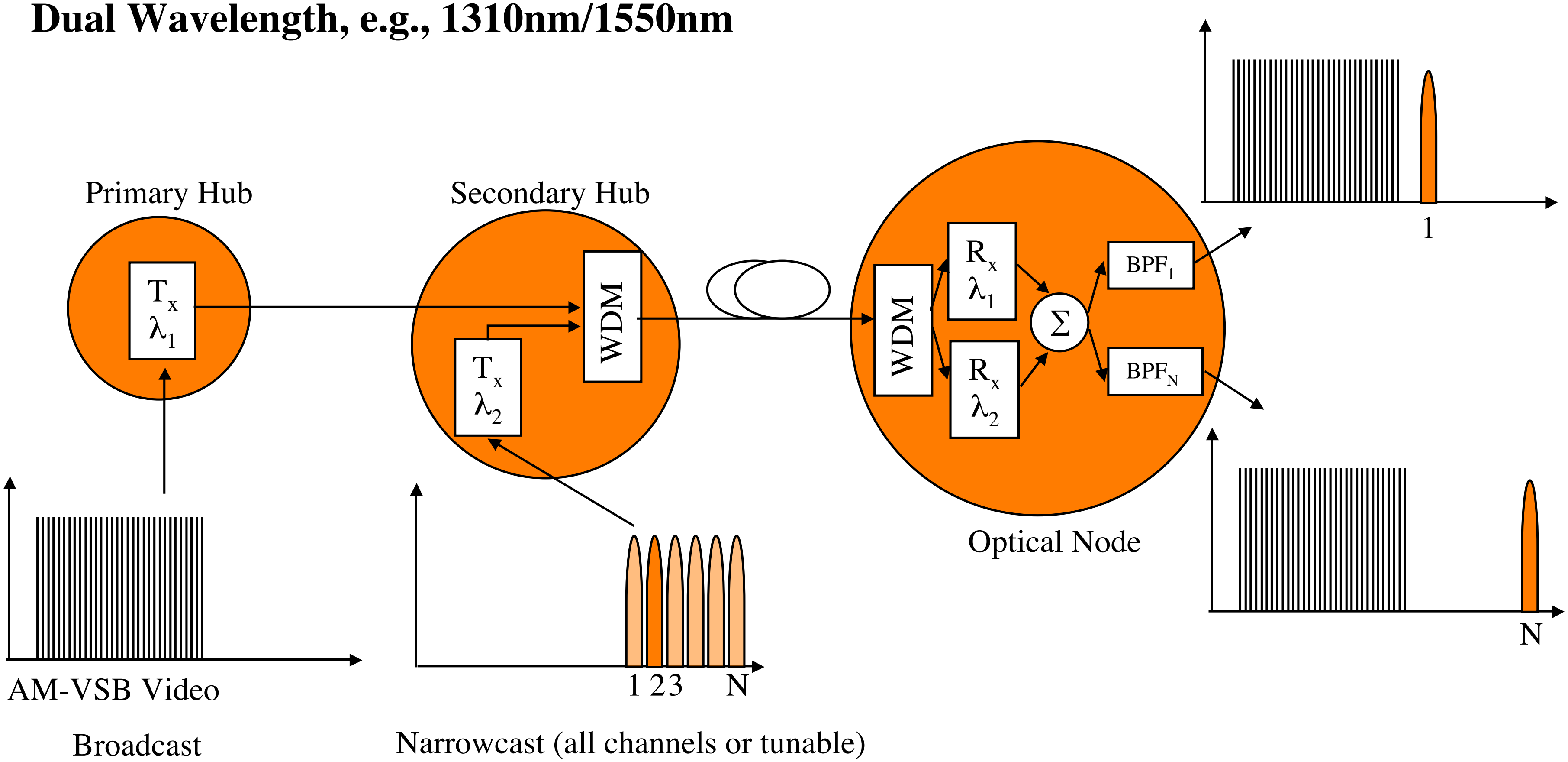
Hybrid Fiber/Coax

Narrowcast + Broadcast Transmission over Fiber: Single Wavelength

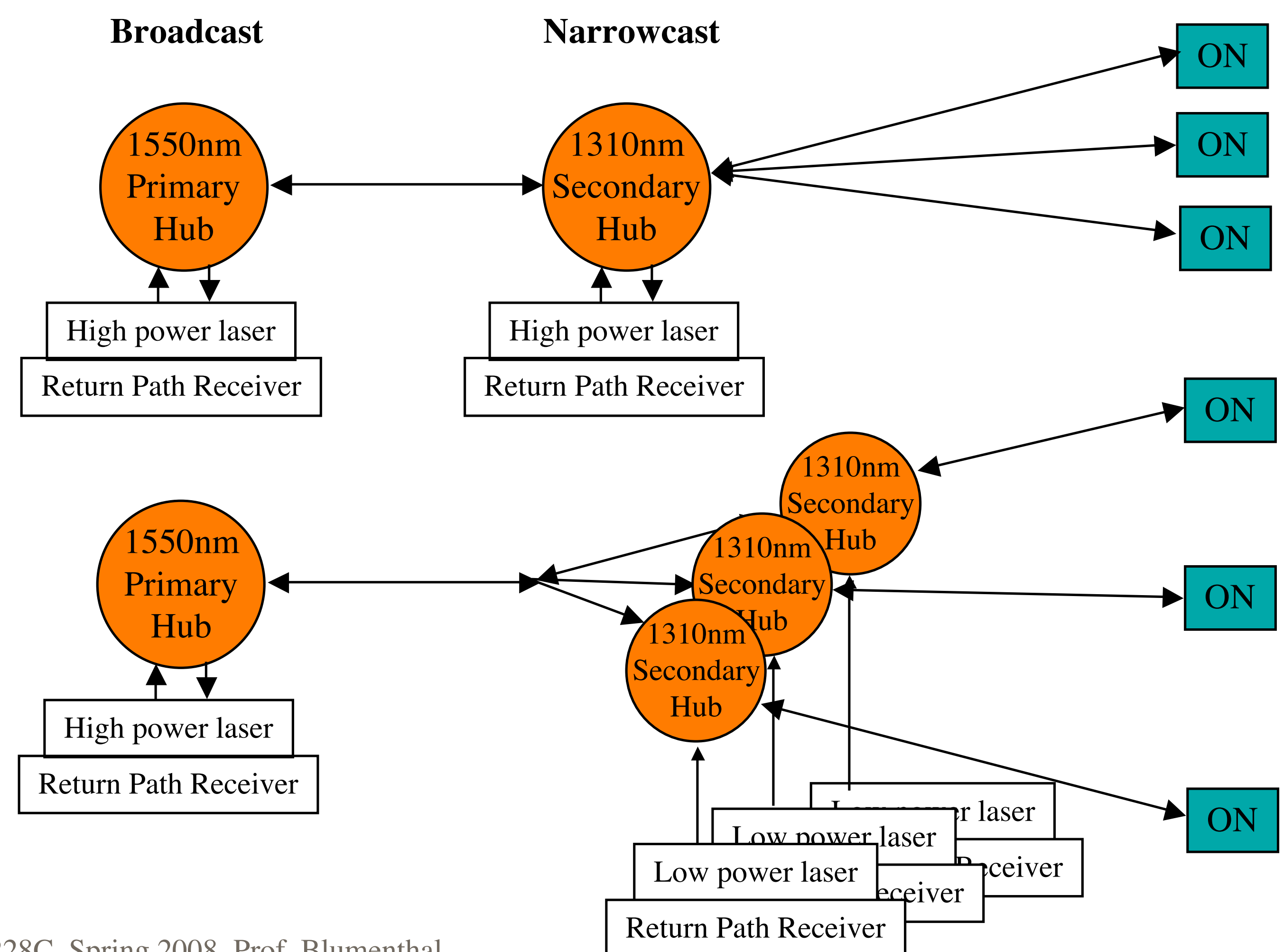


Hybrid Fiber/Coax

Narrowcast + Broadcast Transmission over Fiber:
Dual Wavelength, e.g., 1310nm/1550nm



Hybrid Fiber/Coax Architectures



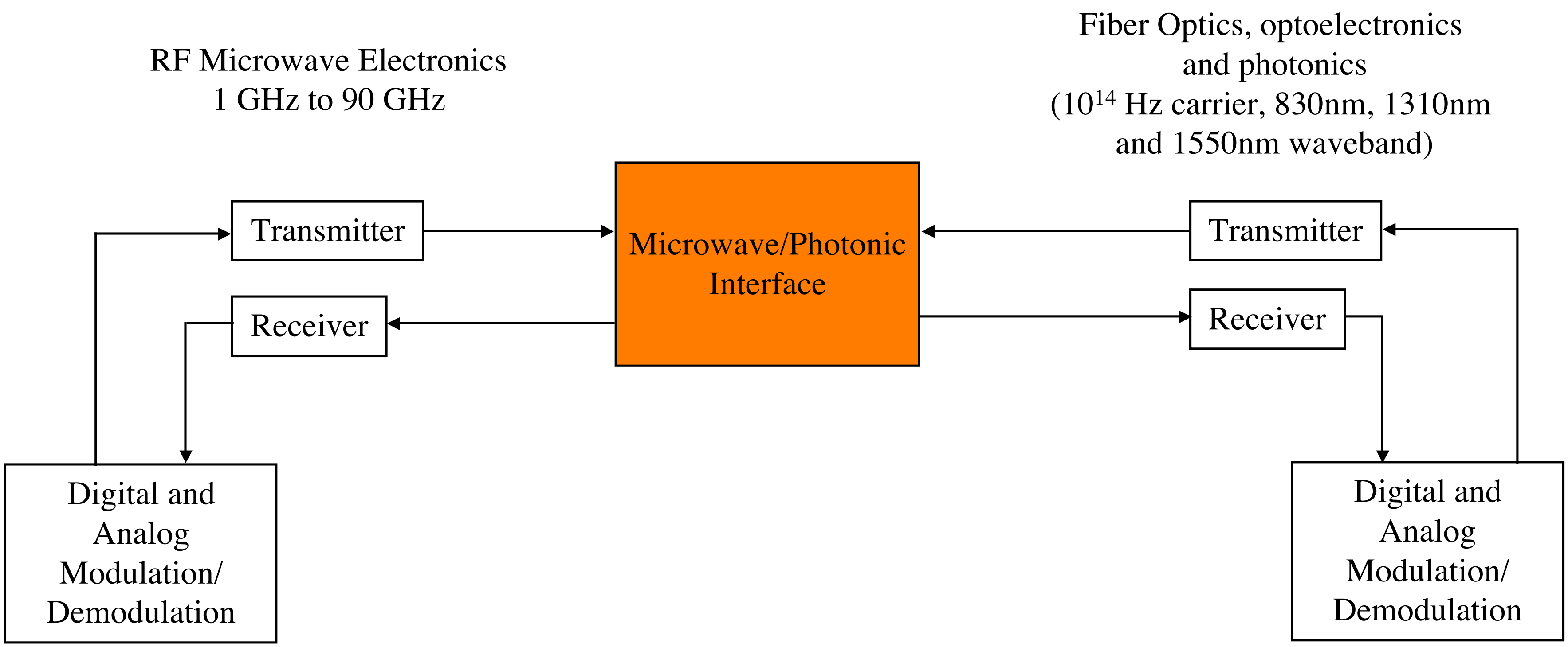
Hybrid Fiber/Coax Performance Issues

- Return path problems
  - Noise returns from customer premises (Ingress Noise)
  - EMI from power transients (Impulse Noise)
- Nonlinear distortions
  - Transmitter (directly modulated laser clipping, laser relaxation oscillation, laser chirp, external modulator nonlinearity)
  - Optical Fiber (fiber nonlinearities, laser chirp combined with fiber dispersion, phase induced intensity noise)
  - Optical amplifier (gain nonlinearities, gain tilt)
  - Optical elements (polarization dependence, linearity)
- Performance measured for analog signals in terms of carrier-to-noise ratio (CNR) and spurious free dynamic range (SFDR).

Return Path (Up-Link Transmission)

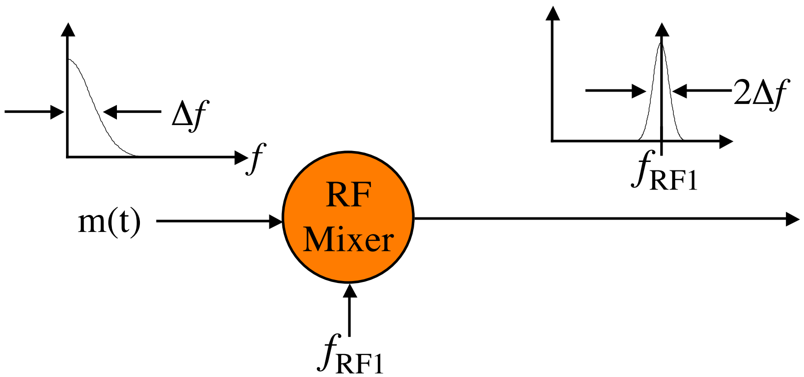
- In all these architecture, the high bandwidth traffic flows from the central hub to the final users
- Anyway, in most application, a return path is required to set-up a bi-directional link, typically for
  - Standard voice application
  - IP transmission
- Several proposed architectures uses the same fiber bi-directional, to implement both down- and up-link traffic on the same fiber
  - Usually, two different wavelengths are used in the two directions (1300 and 1550 nm)
  - The bi-directional solution is efficient, but introduces several transmission issues

Microwave/Photonic Interfaces

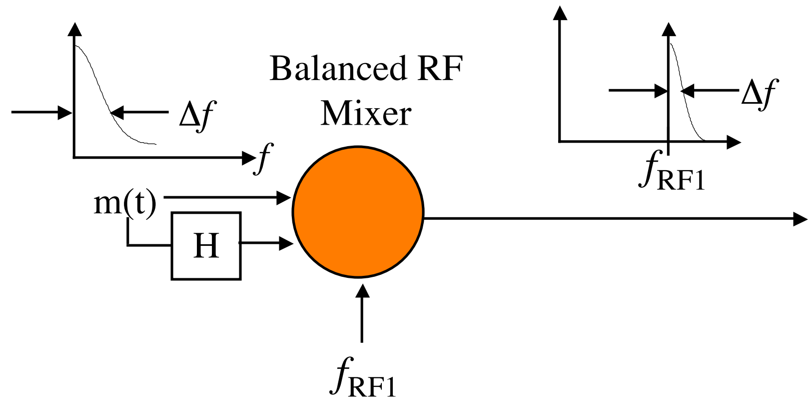


Subcarrier Multiplexing

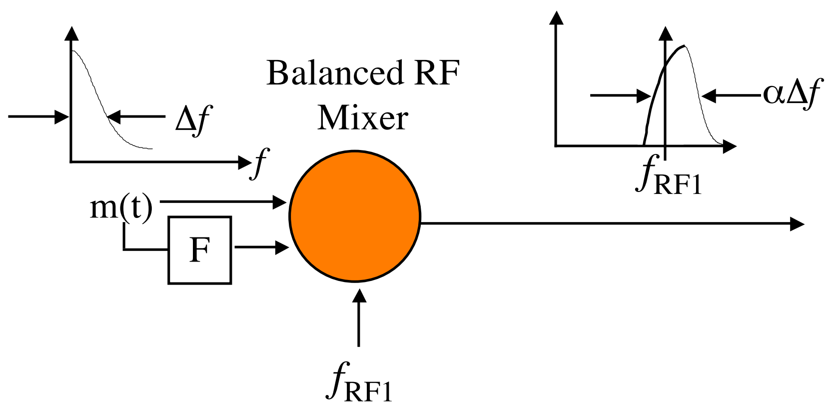
Double Sideband (DSB) Modulation



Single Sideband (SSB) Modulation

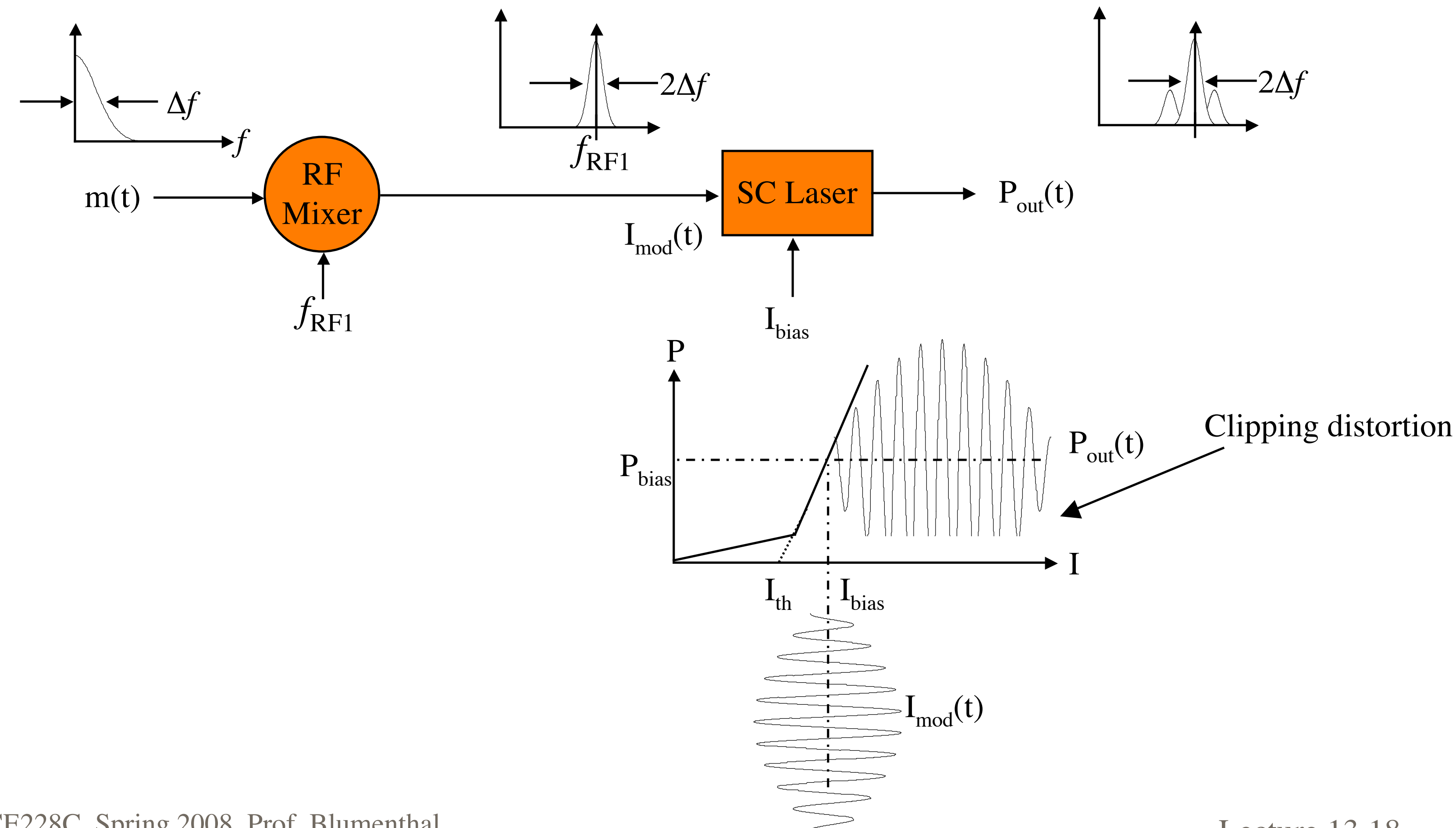


Vestigial Sideband (VSB) Modulation

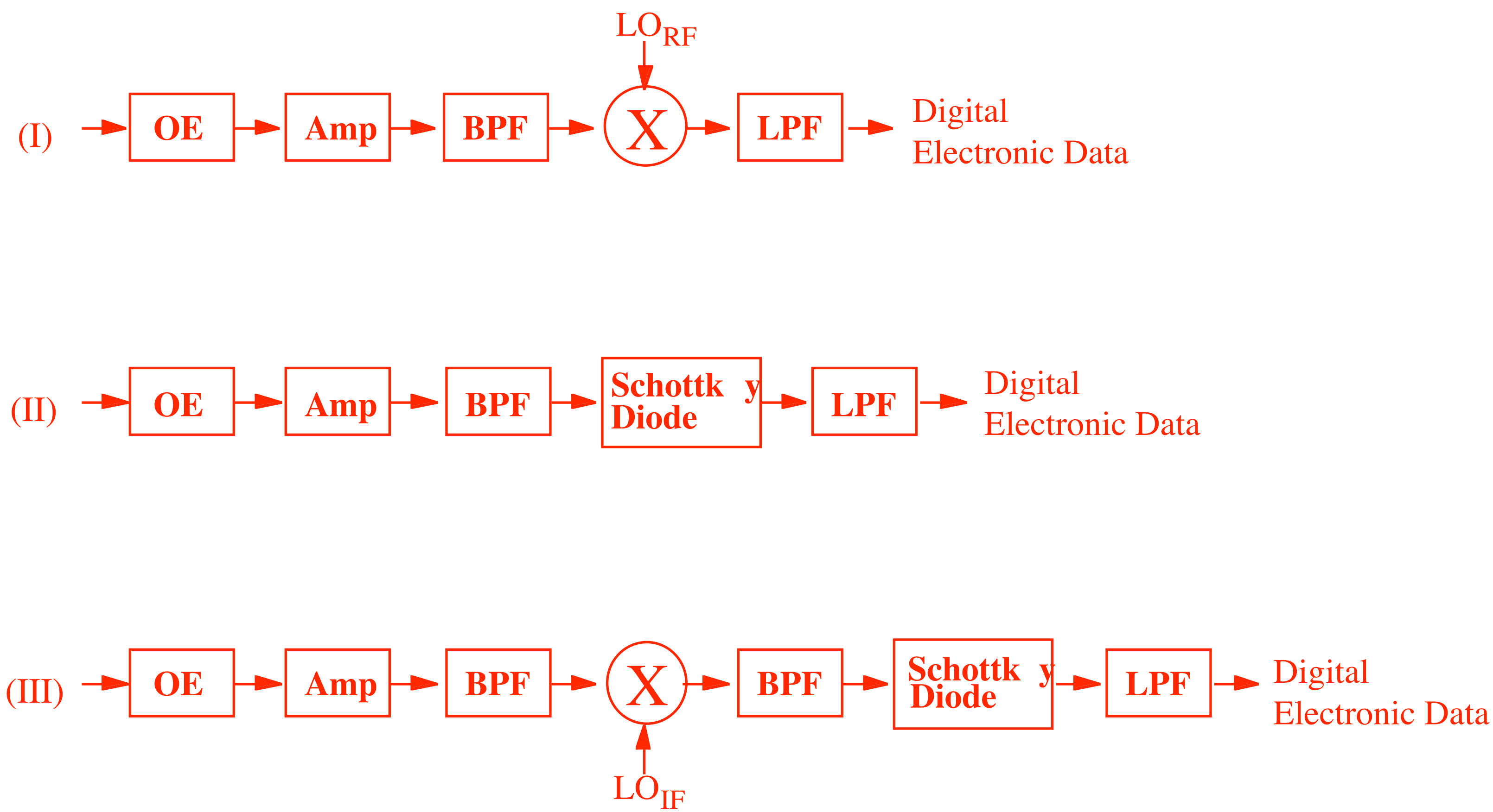


Optical Subcarrier Multiplexing

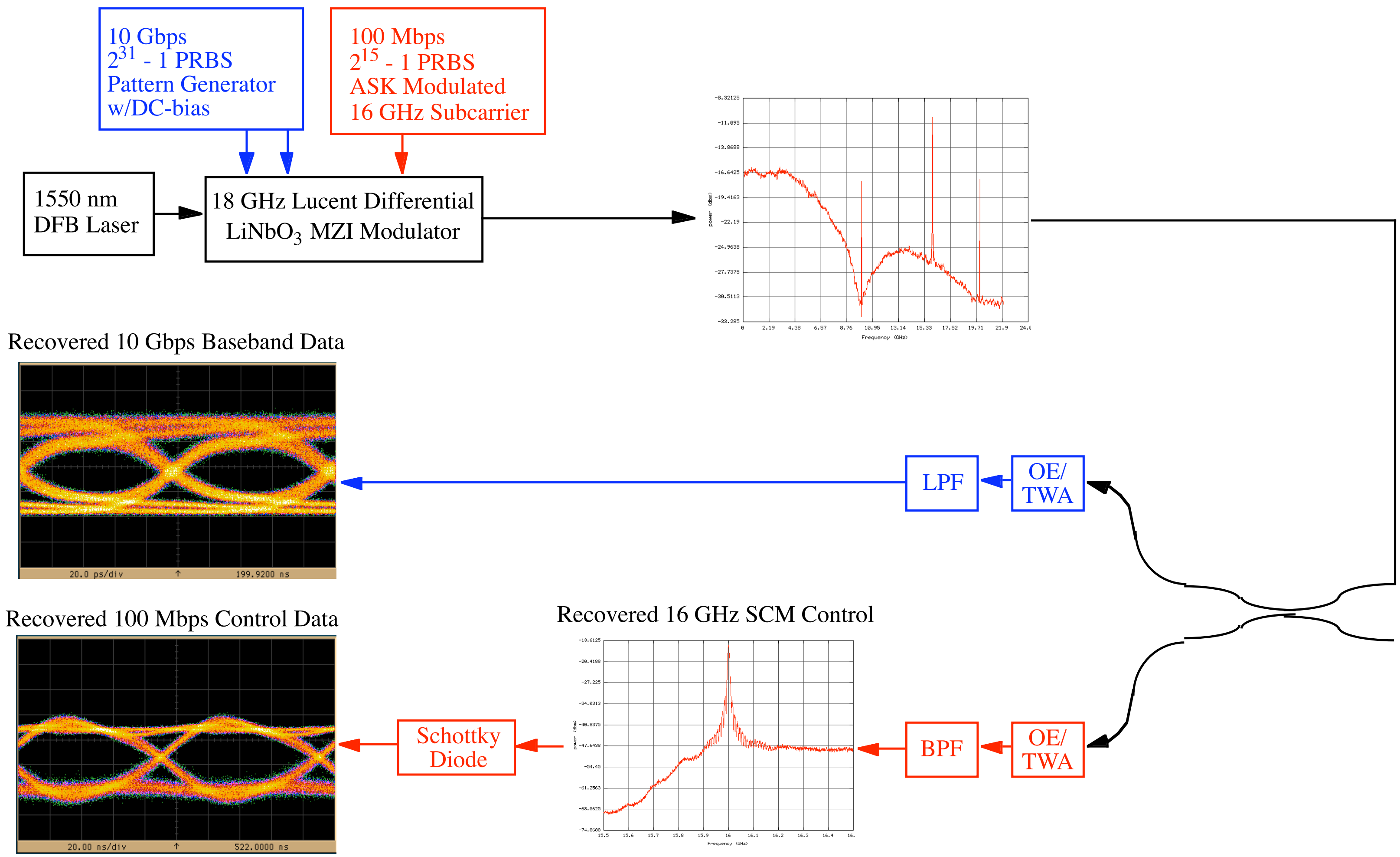
Direct Modulation



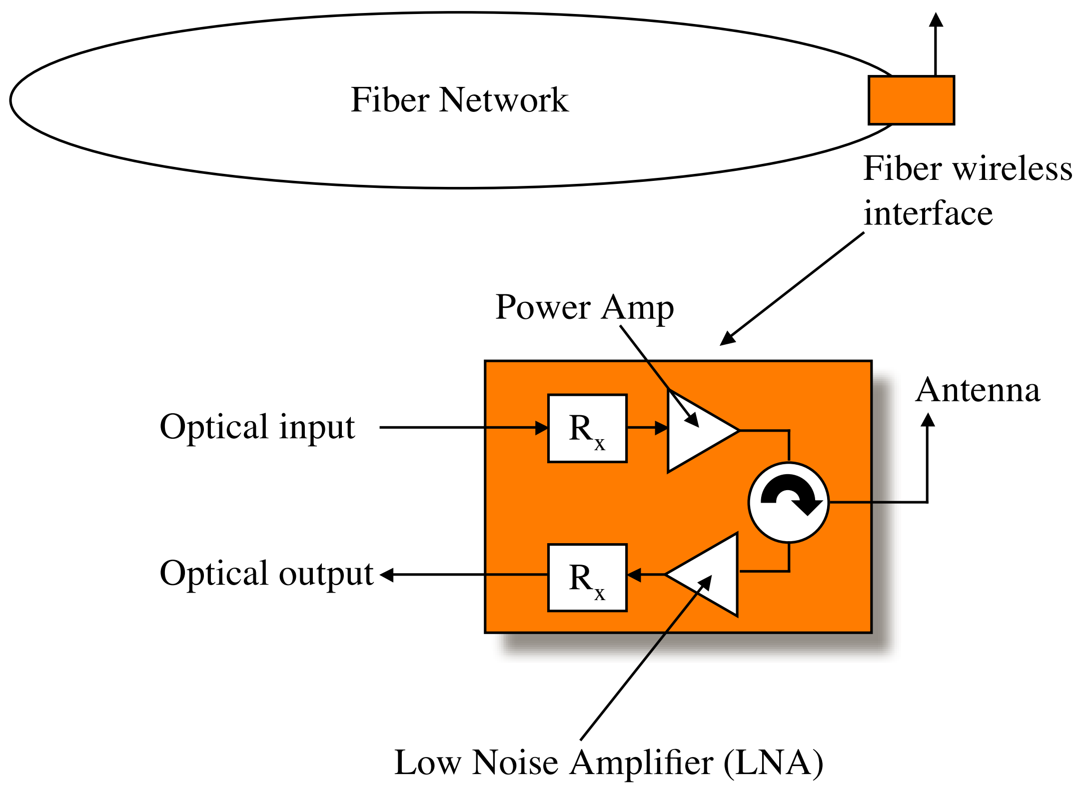
Digital OSCM Receivers



High Bandwidth Mixed Signal Transmitter

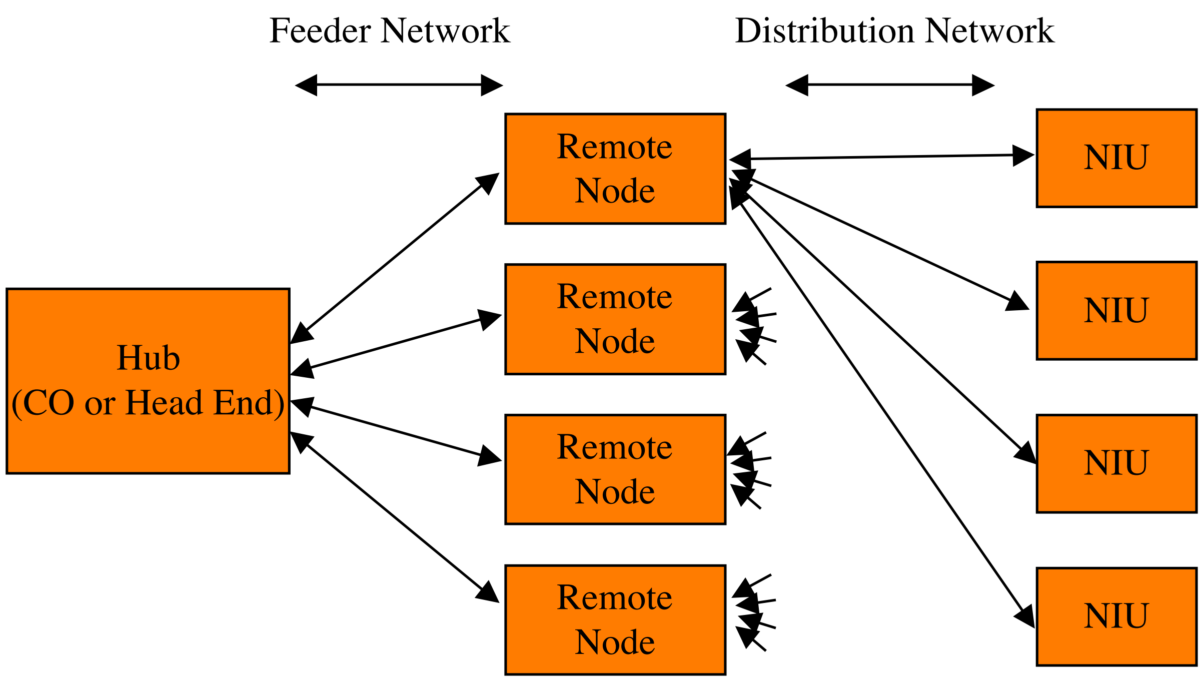


Fiber Wireless Networks

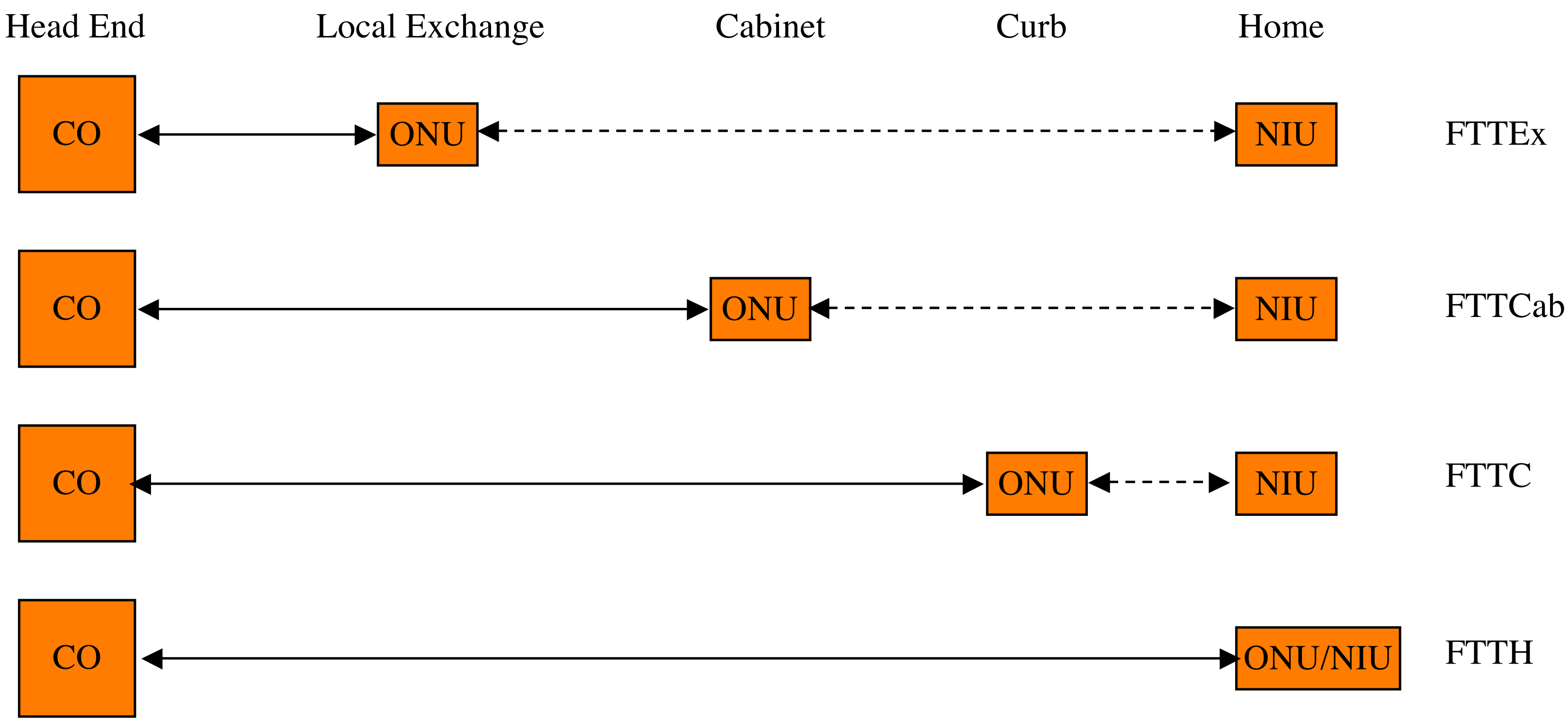


Access Networks

- Access networks represent the last mile in getting bandwidth to the end user (home, office, etc.)
- These networks must form a bridge between the high capacity optical networks of the future and the low cost access.



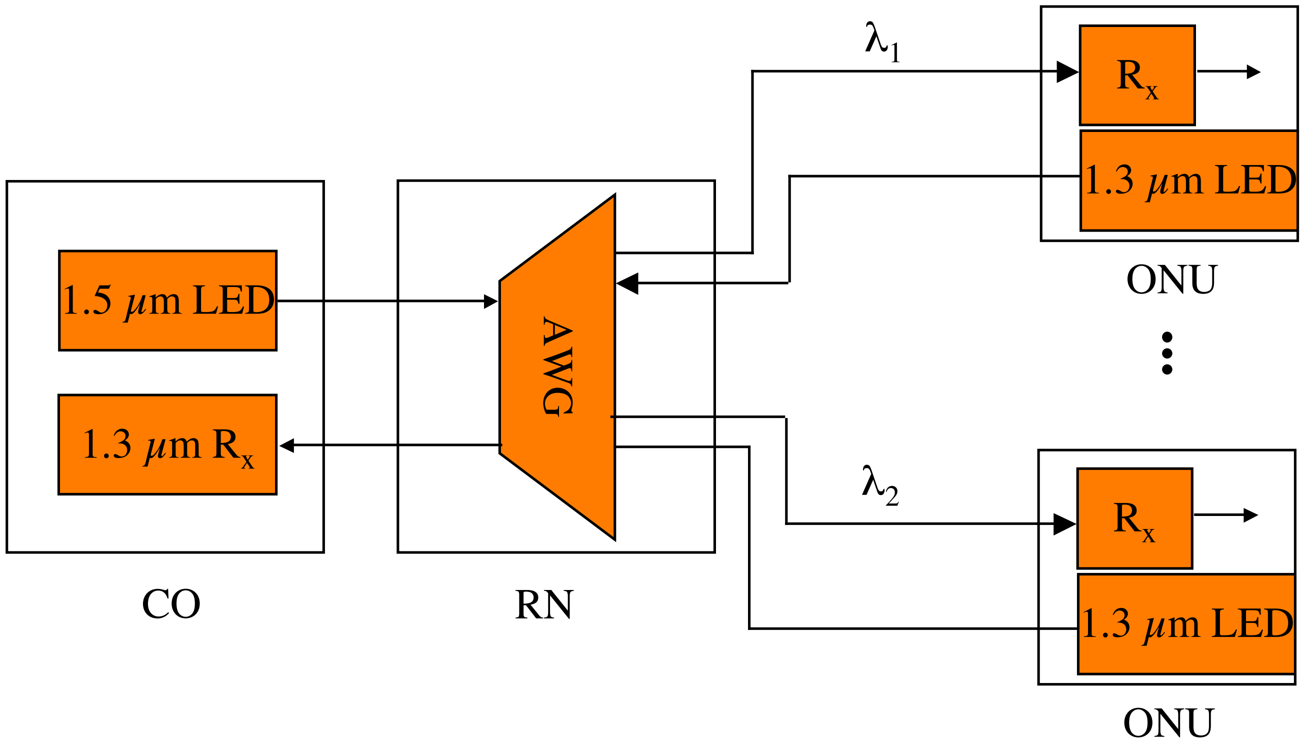
Access Network Types



Adapted from R. Ramaswami, Optical Networks, Morgan Kaufmann.

Example PON

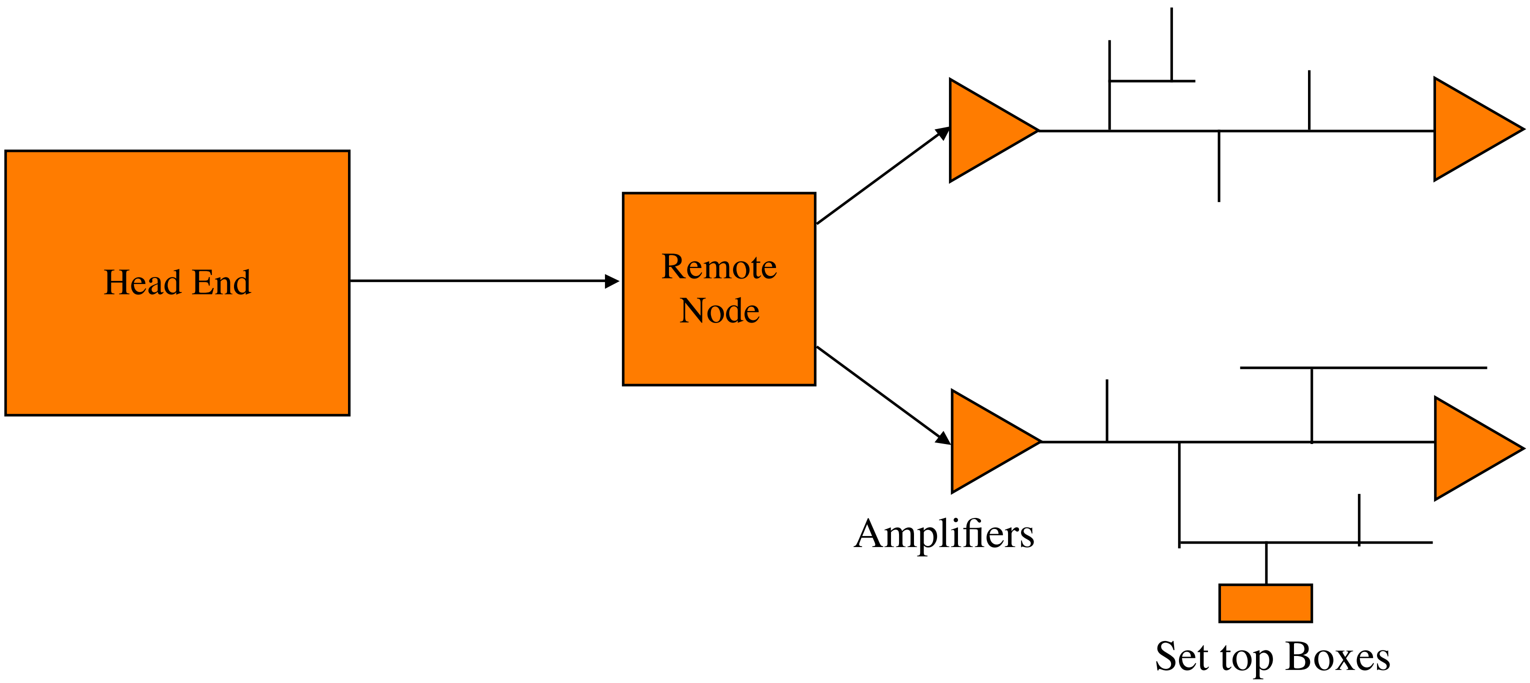
LARNET WRPON



M. Zirnigibl et. Al., LARnet, a local access router network, IE PTL, Vol..7, p. 1041, Feb. 1995.

Cable TV Distribution Networks

Hybrid Fiber Coax: Through Subcarrier Modulated Fiber Coax Bus (SMFCB)



GPON Transceiver Standards

Downstream/Upstream Rates

- 1244.16 Mbps/155.52 Mbps
- 1244.16 Mbps/622.08 Mbps
- 1244.16 Mbps/1244.16 Mbps
- 2488.32 Mbps/155.52 Mbps
- 2488.32 Mbps/622.08 Mbps
- 2488.32 Mbps/1244.16 Mbps
- 2488.32 Mbps/ 2488.32 Mbps

Operating Wavelength

- Downstream
  - Single Fiber: 1480 - 1500nm
  - Dual Fiber: 1260 - 1360nm
- Upstream
  - 1260 - 1360nm

Physical Medium Dependent Parameters

- Attenuation Range
  - Class A: 5 - 20dB
  - Class B: 10 - 25dB
  - Class C: 15 - 30dB
- Differential Optical Path Loss: 15 dB
- Max Optical Path Penalty: 1 dB
- Max differential logical reach: 20 km
- Max fiber distance between S/R and R/S points: 20 km
- Bi-directional transmission: 1 fiber WDM or 2 fiber

Single Fiber OLT Transmitter 1244 Mbps Downstream

- Operating wavelength: 1480 - 1500 (SF)
- Line Code: Scrambled NRZ
- Mean Launch Power (dBm)
  - Class A: -4 min, +1 max
  - Class B: +1 min, +6 max
  - Class C: +5 min, +9 max
- Extinction Ratio: > 10 dB
- Tolerance to transmitter incident light power: > -15 dB
- SLM laser linewidth: 1 nm max @ -20 dB
- SLM laser SMSR: 30 dB min

Single Fiber ONU Receiver 1244 Mbps Downstream

- Minimum reflectance: <20 dB @ Rx wavelength
- BER: $< 10^{-10}$
- Minimum Sensitivity/Minimum Overload (dBm)
  - Class A: -25/-4
  - Class B: -25/-4
  - Class C: -26/-4
- Consecutive identical gain immunity: > 72 bit
- Jitter tolerance
- Tolerance to reflected optical power: < 10 dB

Single Fiber OLT Transmitter 2488 Mbps Downstream

- Operating wavelength: 1480 - 1500 (SF)
- Line Code: Scrambled NRZ
- Mean Launch Power (dBm)
  - Class A: 0 min, +4 max
  - Class B: +5 min, +9 max
  - Class C: +3 min, +7 max
- Extinction Ratio: > 10 dB
- Tolerance to transmitter incident light power: > -15 dB
- SLM laser linewidth: 1 nm max @ -20 dB
- SLM laser SMSR: 30 dB min

Single Fiber ONU Receiver 2488 Mbps Downstream

- Minimum reflectance: <20 dB @ Rx wavelength
- BER: $< 10^{-10}$
- Minimum Sensitivity/Minimum Overload (dBm)
  - Class A: -21/-1
  - Class B: -21/-1
  - Class C: -28/-8
- Consecutive identical gain immunity: > 72 bit
- Jitter tolerance
- Tolerance to reflected optical power: < 10 dB

Single Fiber ONU Transmitter 155 Mbps Upstream

- Operating wavelength: 1260 - 1360 (SF)
- Line Code: Scrambled NRZ
- Maximum reflectance: <-6 dB @ Tx wavelength
- Mean Launch Power (dBm)
  - Class A: -6 min, 0 max
  - Class B: -4 min, +2 max
  - Class C: -2 min, +4 max
- Launched power without input: Min Sens - 10 dBm
- Max Tx enable/disable: 2/2 bits
- Extinction Ratio: > 10 dB
- Tolerance to transmitter incident light power: > -15 dB
- SLM laser linewidth: 1 nm max @ -20 dB
- SLM laser SMSR: 30 dB min
- Jitter transfer
- Jitter generation: 0.2 p-p from 0.5kHz to 1.3MHz

Single Fiber OLT Receiver 155 Mbps Upstream

- Minimum reflectance: <20 dB @ Rx wavelength
- BER: $< 10^{-10}$
- Minimum Sensitivity/Minimum Overload (dBm)
  - Class A: -27/-5
  - Class B: -30/-8
  - Class C: -33/-11
- Consecutive identical gain immunity: > 72 bit
- Jitter tolerance: NA
- Tolerance to reflected optical power: < 10 dB

Single Fiber ONU Transmitter 622 Mbps Upstream

- Operating wavelength: 1260 - 1360
- Line Code: Scrambled NRZ
- Maximum reflectance: <-6 dB @ Tx wavelength
- Mean Launch Power (dBm)
  - Class A: -6 min, -1 max
  - Class B: -1 min, +4 max
  - Class C: -1 min, +4 max
- Launched power without input: Min Sens - 10 dBm
- Max Tx enable/disable: 8/8 bits
- Extinction Ratio: > 10 dB
- Tolerance to transmitter incident light power: > -15 dB
- SLM laser linewidth: 1 nm max @ -20 dB
- SLM laser SMSR: 30 dB min
- Jitter transfer
- Jitter generation: 0.2 p-p from 0.5kHz to 1.3MHz

Single Fiber OLT Receiver 622 Mbps Upstream

- Minimum reflectance: <20 dB @ Rx wavelength
- BER: < 10^{-10}
- Minimum Sensitivity/Minimum Overload (dBm)
  - Class A: -27/-6
  - Class B: -27/-6
  - Class C: -32/-11
- Consecutive identical gain immunity: > 72 bit
- Jitter tolerance: NA
- Tolerance to reflected optical power: < 10 dB

Single Fiber ONU Transmitter 1244 Mbps Upstream

- Operating wavelength: 1260 - 1360
- Line Code: Scrambled NRZ
- Maximum reflectance: <-6 dB @ Tx wavelength
- Mean Launch Power min/max(dBm)
  - Class A: -3/+2; Power Leveling: -2/+3
  - Class B: -2/+3; Power Leveling: -2/+3
  - Class C: +2/+7; Power Leveling: +2/+7
- Launched power without input: Min Sens - 10 dBm
- Max Tx enable/disable: 16/16 bits
- Extinction Ratio: > 10 dB
- Tolerance to transmitter incident light power: > -15 dB
- SLM laser linewidth: 1 nm max @ -20 dB
- SLM laser SMSR: 30 dB min
- Jitter transfer
- Jitter generation: 0.33 p-p from 4.0kHz to 10.0MHz

Single Fiber OLT Receiver 1244 Mbps Upstream

- Minimum reflectance: <20 dB @ Rx wavelength
- BER: $< 10^{-10}$
- Minimum Sensitivity/Minimum Overload (dBm)
  - Class A: -24/-3; Power Leveling: -23/-8
  - Class B: -28/-7; Power Leveling: -28/-13
  - Class C: -29/-8; Power Leveling: -29/-14
- Consecutive identical gain immunity: > 72 bit
- Jitter tolerance: NA
- Tolerance to reflected optical power: < 10 dB

Single Fiber ONU Transmitter 2488 Mbps Upstream

- Operating wavelength: 1260 - 1360
- Line Code: Scrambled NRZ
- Maximum reflectance: <-6 dB @ Tx wavelength
- Mean Launch Power min/max(dBm)
  - Class A: -?/+?; Power Leveling: -?/+?
  - Class B: -?/+?; Power Leveling: -?/+?
  - Class C: +?/+?; Power Leveling: +?/+?
- Launched power without input: Min Sens - ? dBm
- Max Tx enable/disable: ??/?? bits
- Extinction Ratio: > ? dB
- Tolerance to transmitter incident light power: > -? dB
- SLM laser linewidth: ? nm max @ -20 dB
- SLM laser SMSR: ? dB min
- Jitter transfer
- Jitter generation: ? p-p from ? kHz to ? MHz

Single Fiber OLT Receiver 2488 Mbps Upstream

- Minimum reflectance: <? dB @ Rx wavelength
- BER: < ?
- Minimum Sensitivity/Minimum Overload (dBm)
  - Class A: ?/?; Power Leveling: ?/?
  - Class B: ?/?; Power Leveling: ?/?
  - Class C: ?/?; Power Leveling: ?/?
- Consecutive identical gain immunity: > ? bit
- Jitter tolerance: NA
- Tolerance to reflected optical power: < ? dB