VPI University Program

Photonics Curriculum Version 7.0

Lecture Series

Analog Cable Access Systems

System2

Module Prerequisites

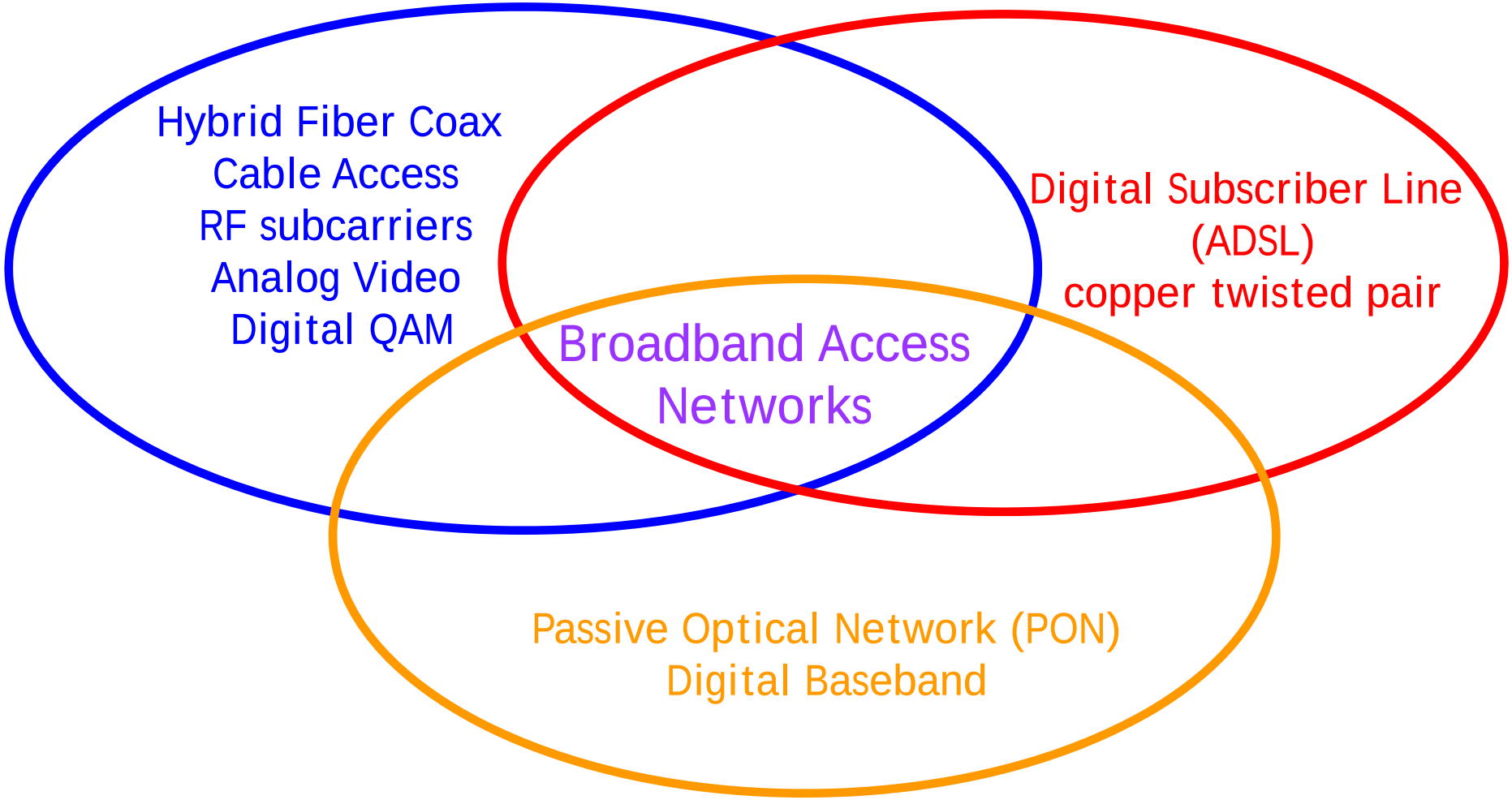
- Introduction to Fiber-Optic Communications I & II
- Fibers I, Transmitters I, Receivers I, Optical Amplifiers I
- Introduction to WDM Systems

Module Objectives

- Introduce different cable access system topologies
- Focus on analog cable access systems
- 2^{nd} & 3^{rd} order harmonic and intermodulation distortions
- Directly modulated CATV transmission systems
- Externally modulated CATV transmission systems
- Optical fiber impairment in CATV transmission

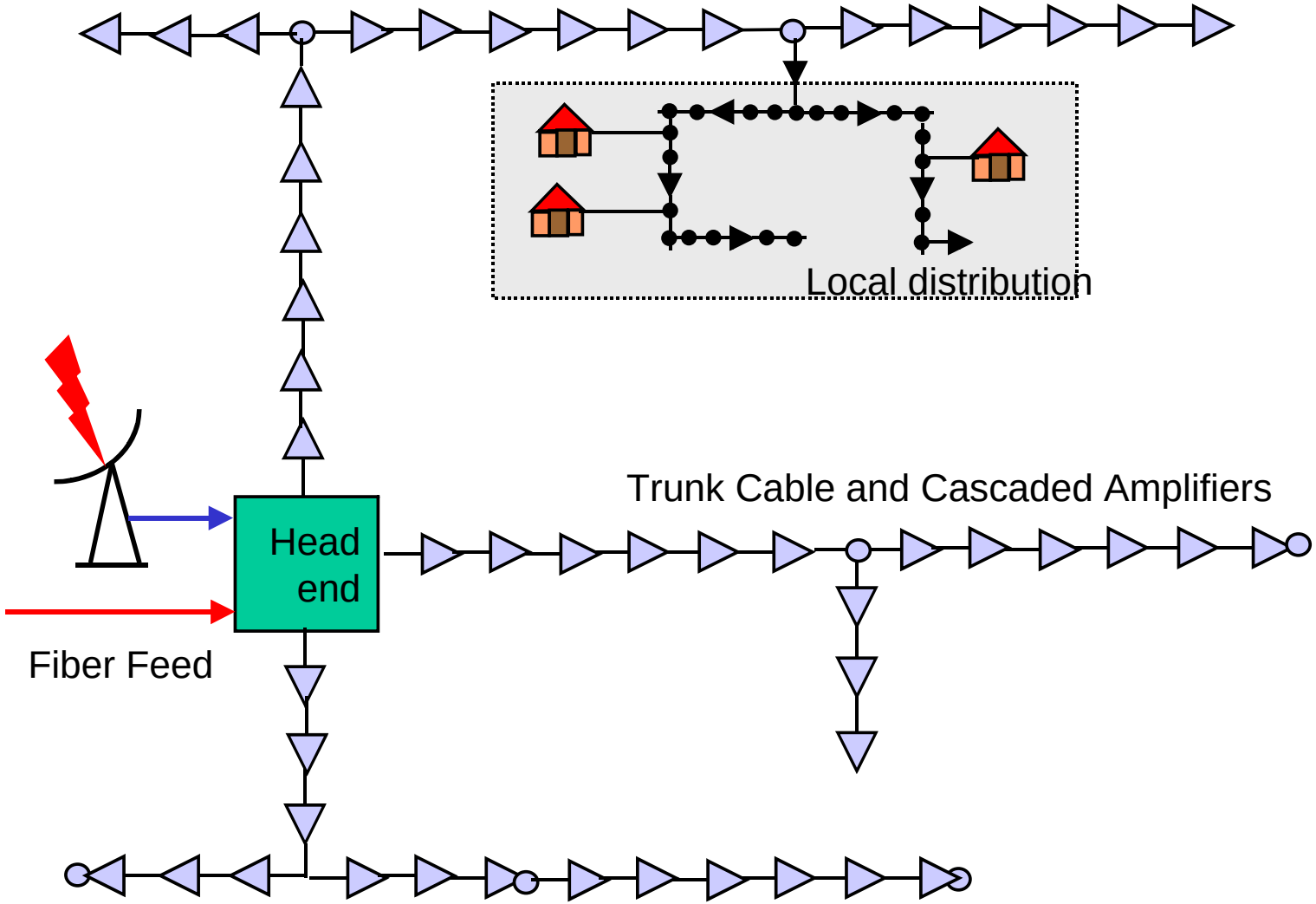
Introduction

Competing Broadband Access Technologies



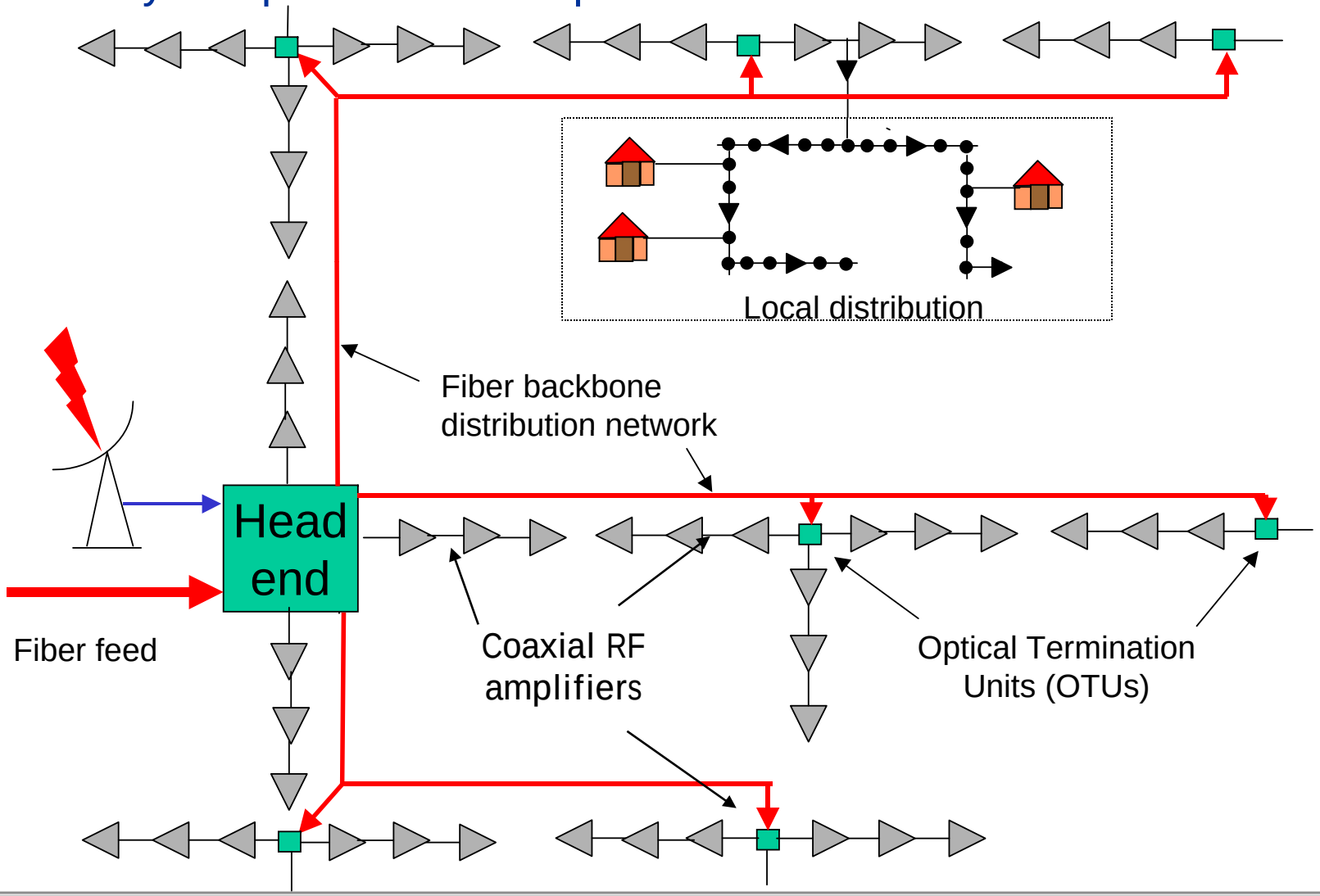
Traditional Coaxial CATV Broadcast Systems

Reliability and distortion problems with many cascaded RF amplifiers



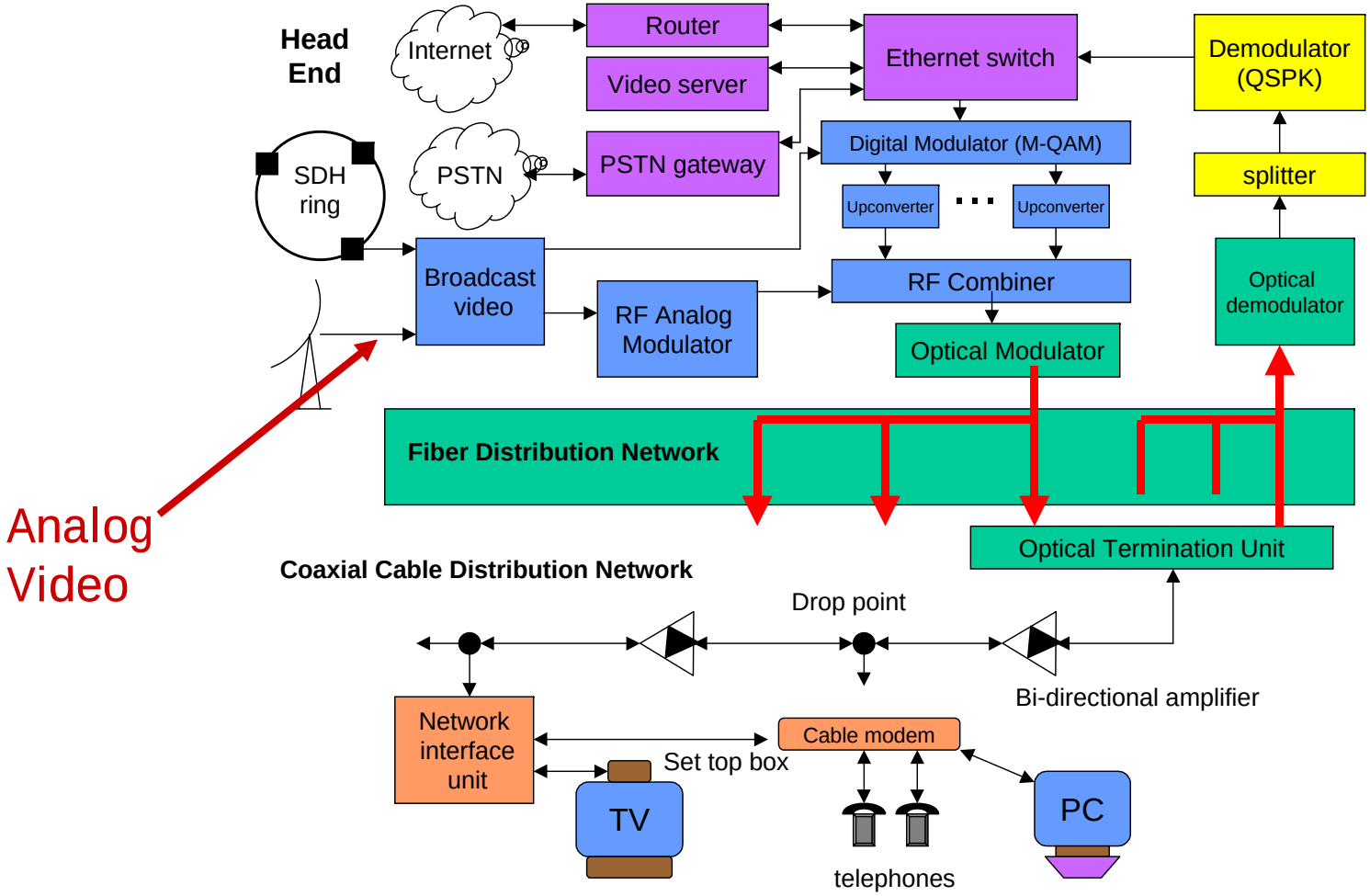
HFC Broadcast System

Reliability and performance improved with fiber feeds to ~ 500 homes

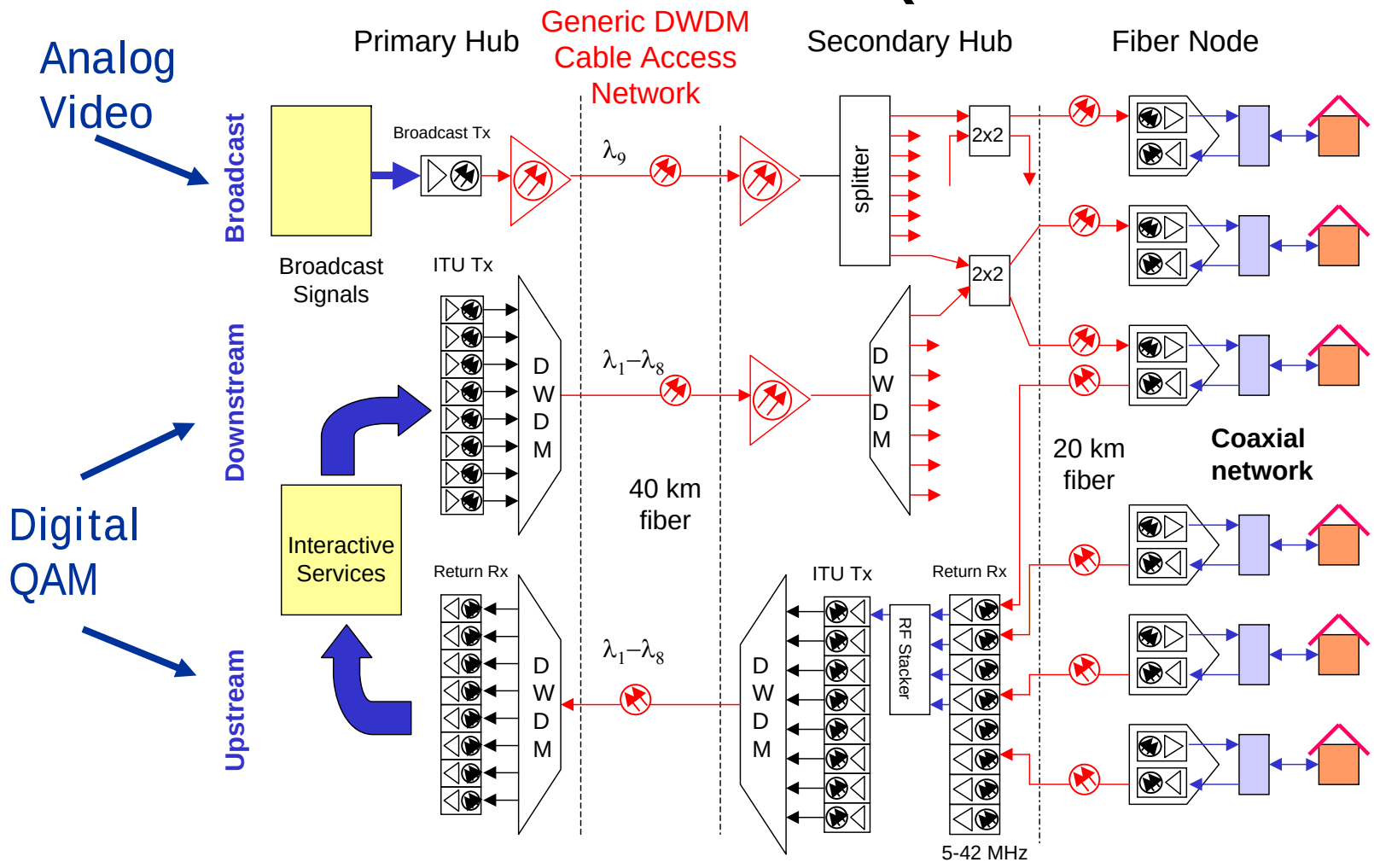


Bidirectional Interactive HFC Cable TV System

A system using one optical downstream channel

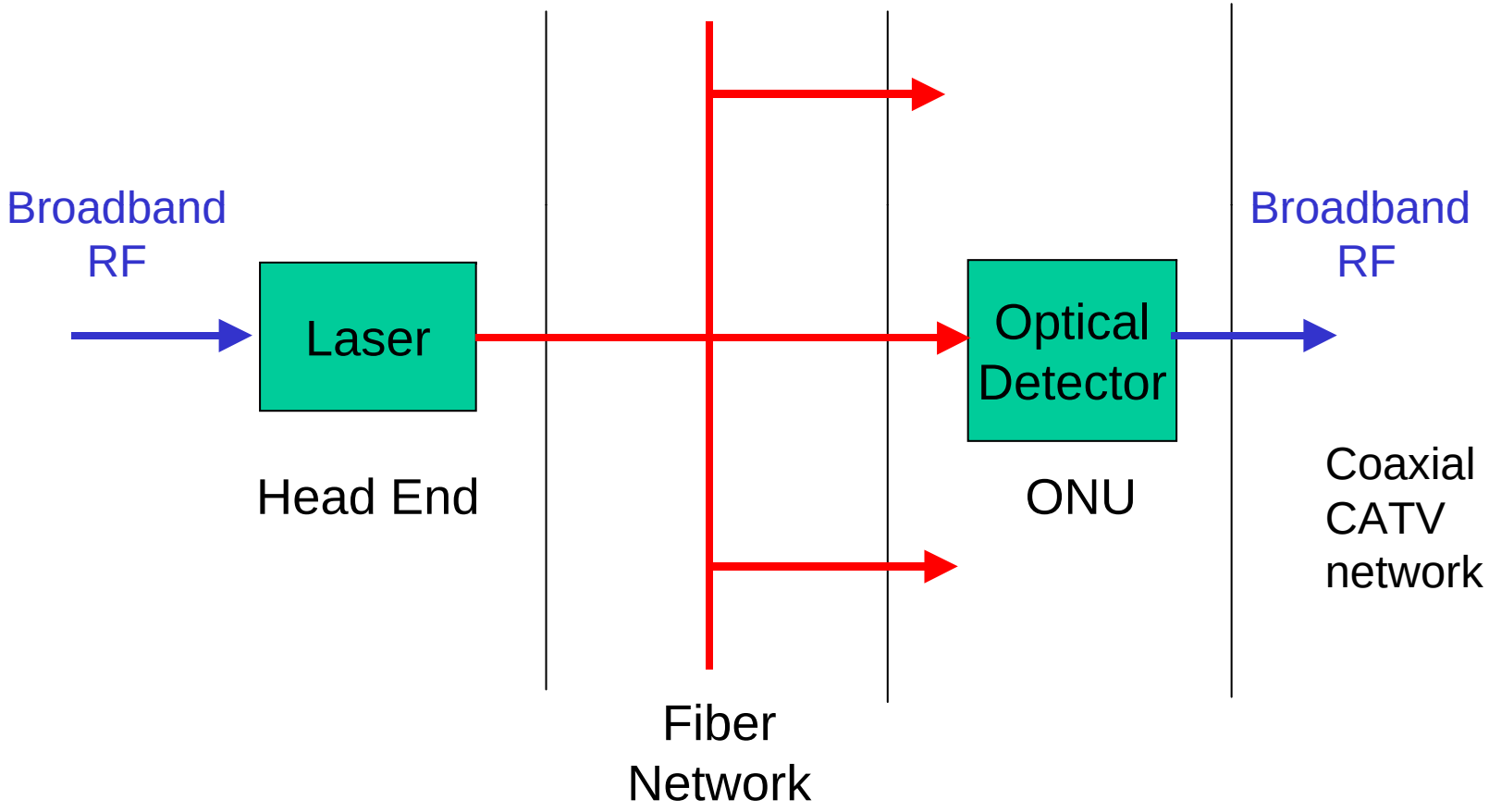


DWDM cable access system (Return-RF stacking)

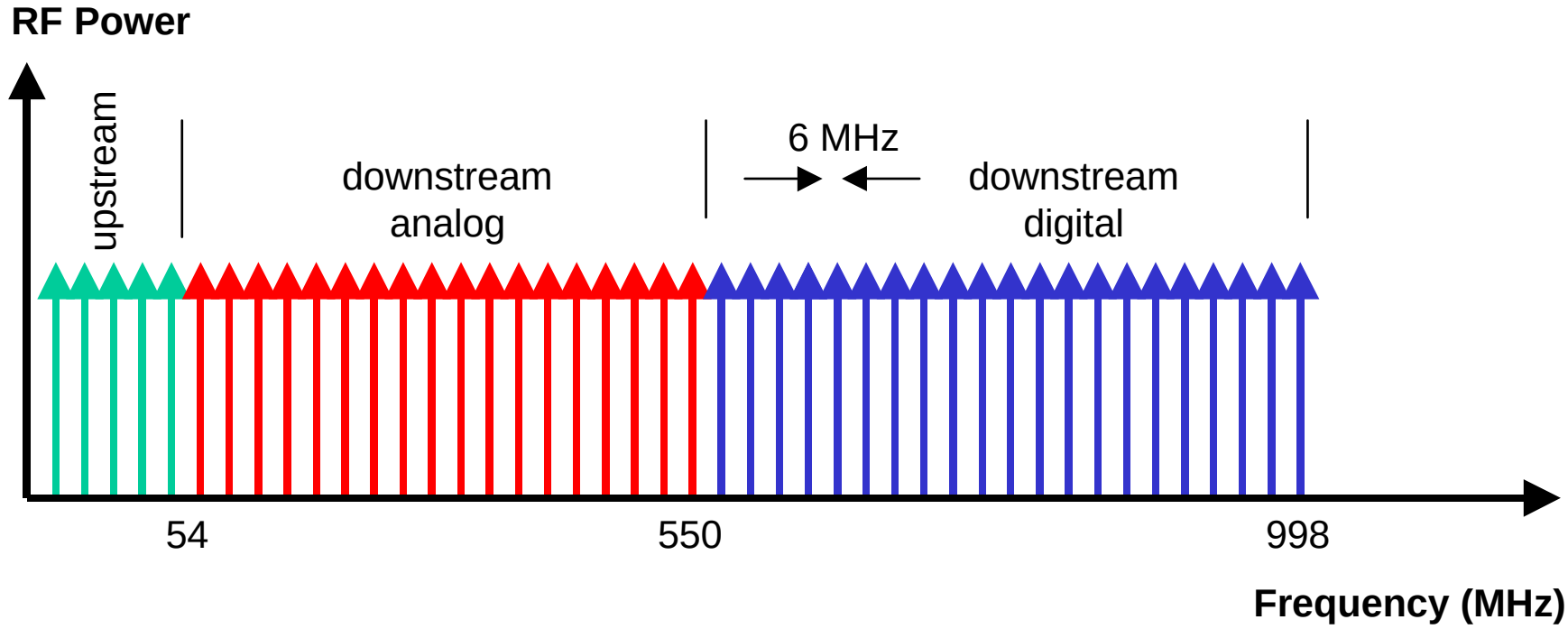


Optical fiber backbone network in an HFC system

basic downstream blocks for simulation



The NTSC CATV frequency plan

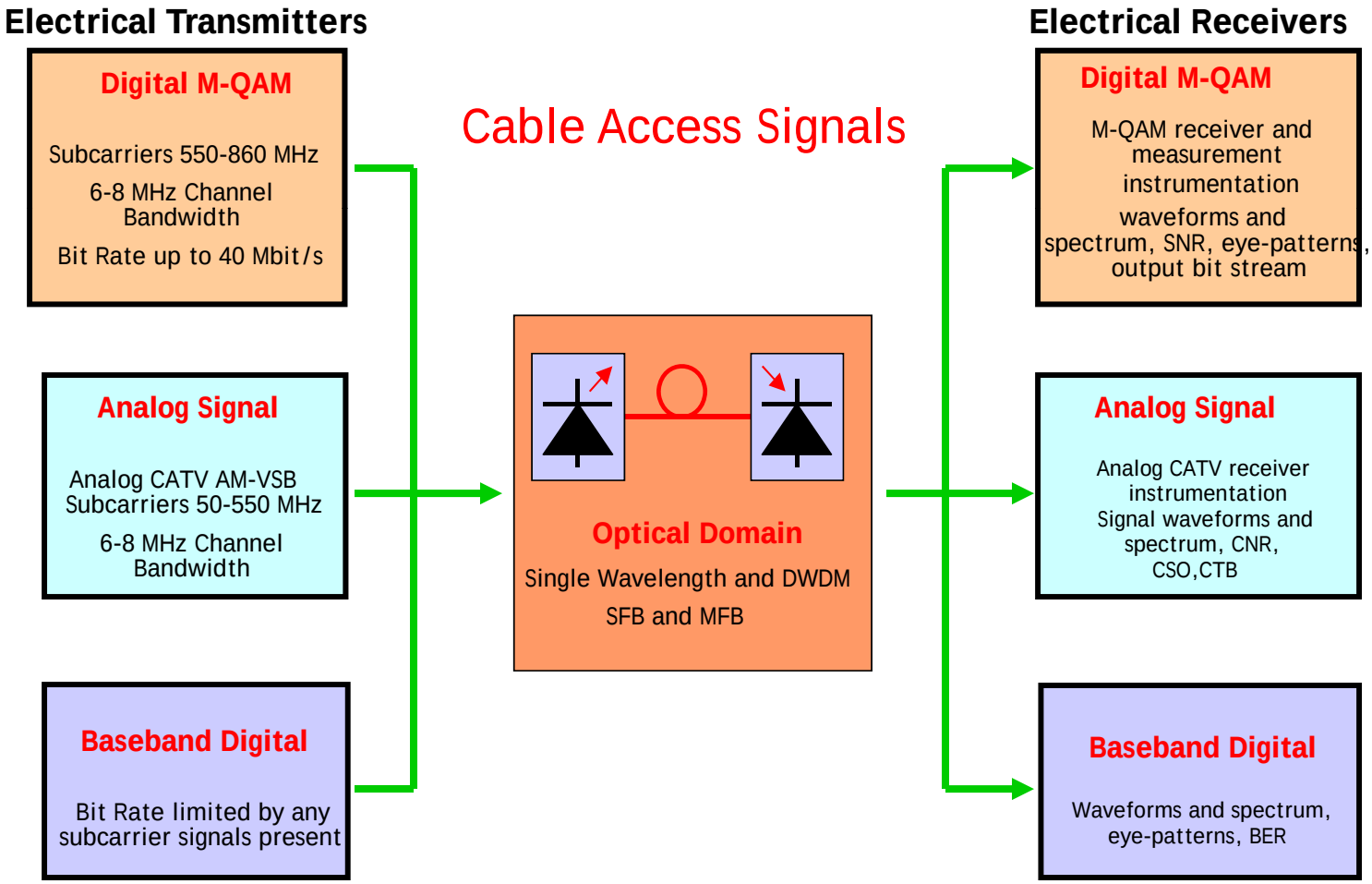


- Carrier frequencies from 55 MHz to 998 MHz
- Channel spacing of 6 MHz

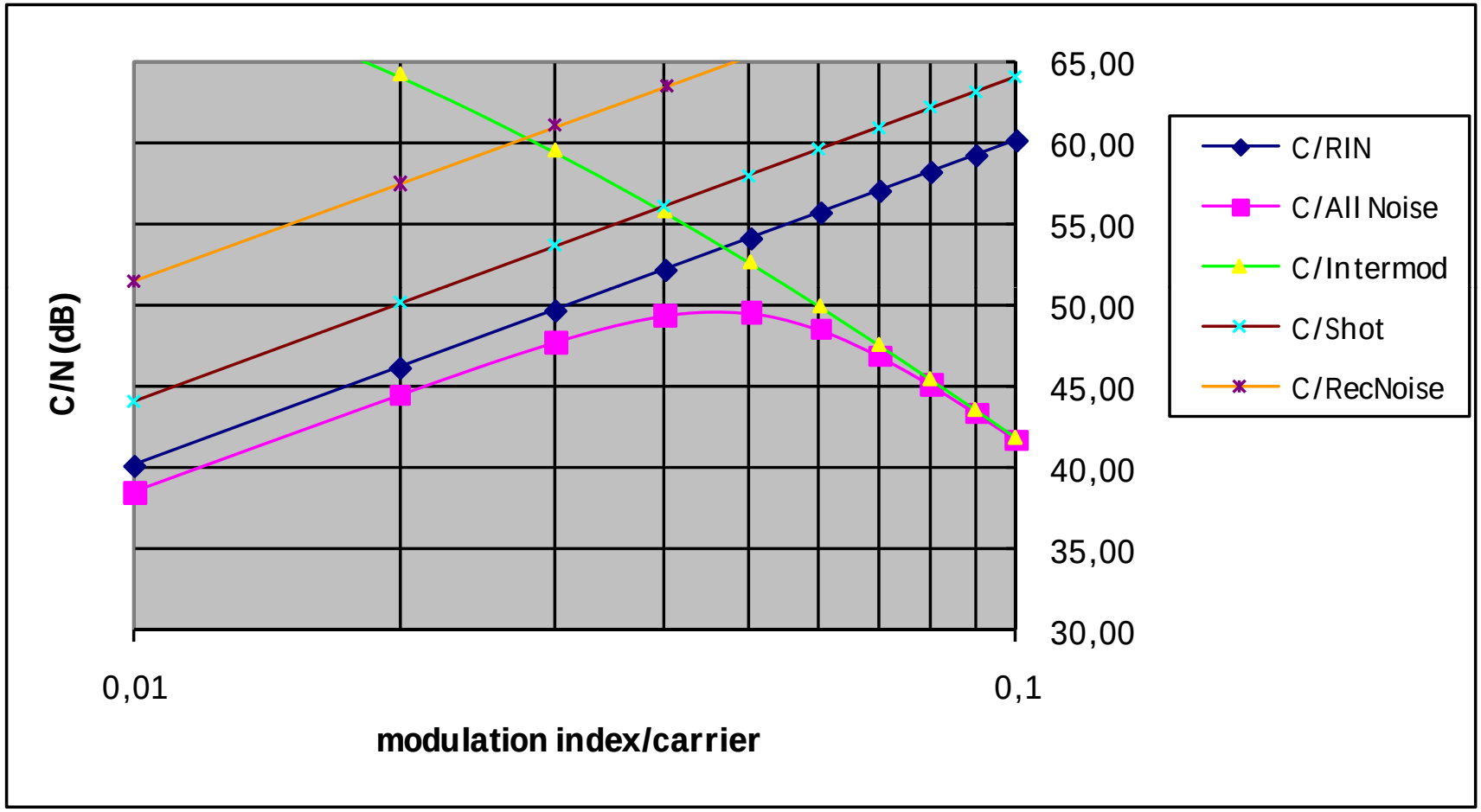
Analog Video Transmission Requirements

- Vestigial sideband amplitude modulation on each carrier (6 MHz apart in an NTSC system).
- Video picture impairment is acceptable if Carrier to Noise Ratio (CNR) > 45 dB.
- Highly susceptible to interference tones arising from nonlinearities in the optical transmission channel.
- Optical transmission/distribution systems - "extremely linear"
- Distortion tone levels > 53 dB below each carrier.
- Performance testing: a "test signal" comprising many un-modulated carriers.

Electrical domain signals interfacing with the optical domain in Cable Access



Typical CNR of NTSC CATV System



Intermodulation Distortion

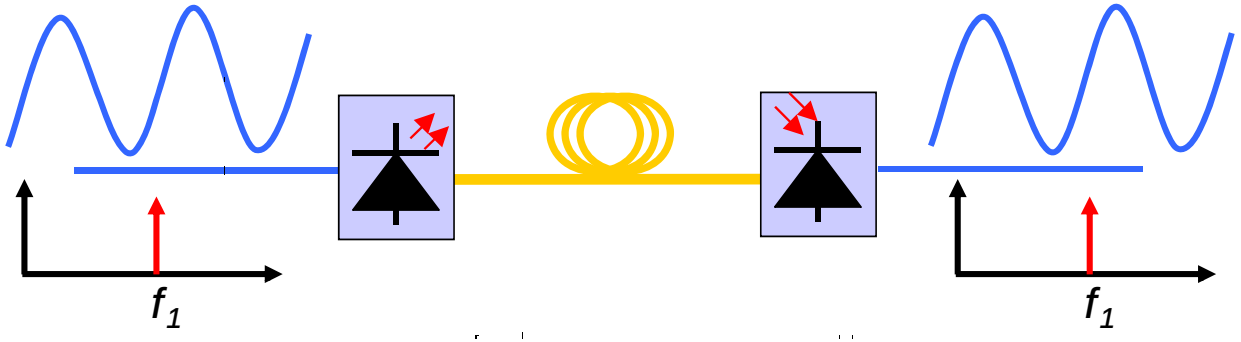
- A dominant cause of CNR degradation
- Caused by transmission nonlinearities
  - In the laser and external modulator

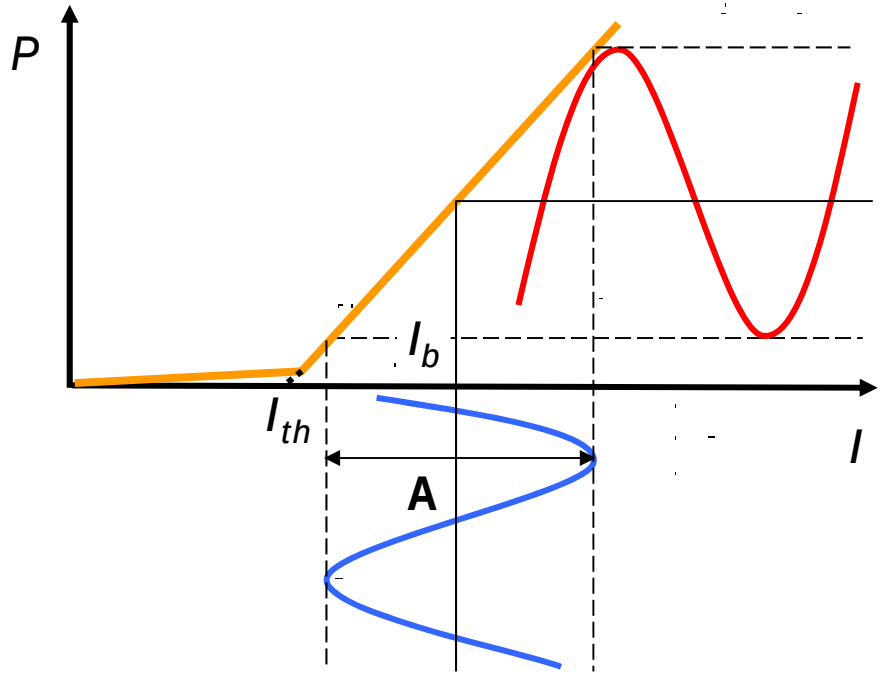
- Second order harmonic and intermodulation distortions
- Third order harmonic and intermodulation distortions

- Laser clipping distortion
- Inversion clipping distortion
- Optical fiber impairment
  - Chirp and dispersion

Directly Modulated CATV Transmission

- A simplified system is shown below

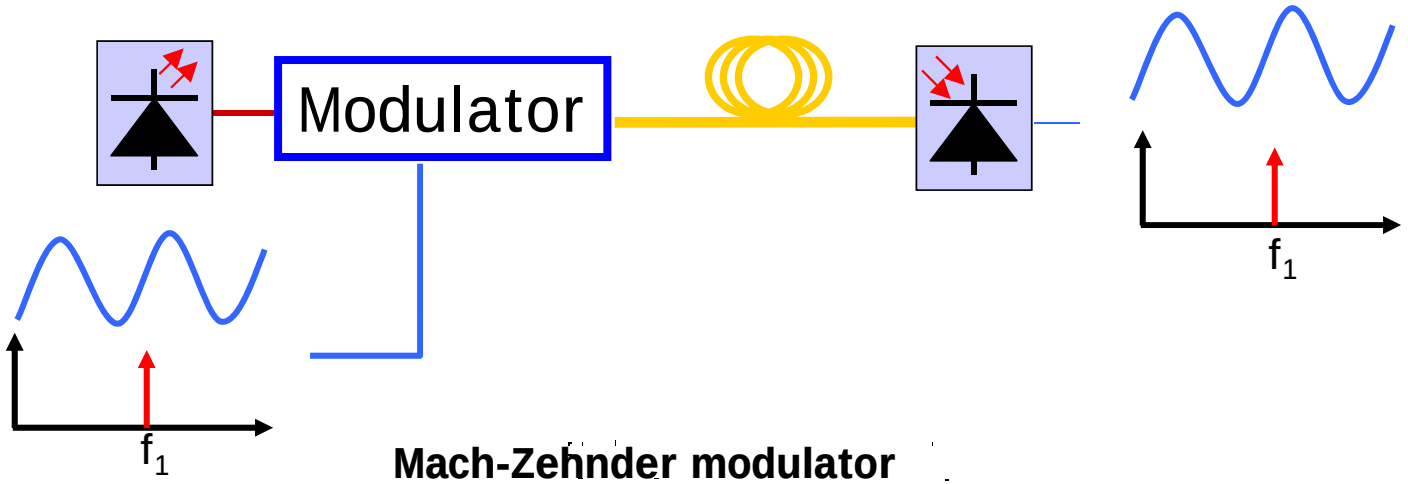




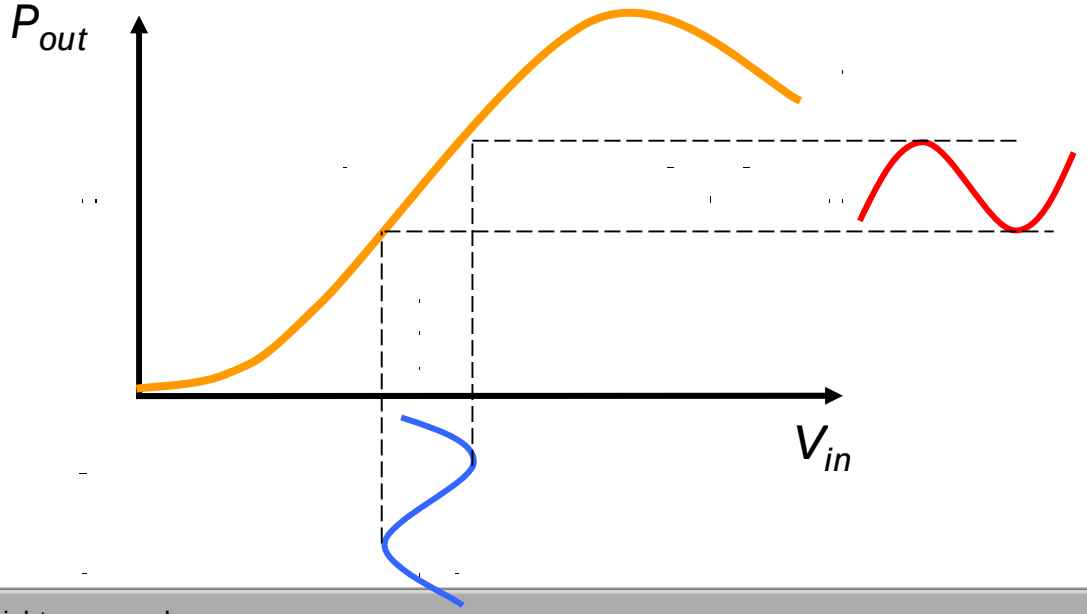
$$I(t) = I_b + I_m \cos(\omega_1 t + \varphi_1)$$

$$m = \frac{I_m}{I_b - I_{th}} = \frac{\frac{I_m}{I_{th}}}{\frac{I_b}{I_{th}} - 1}$$

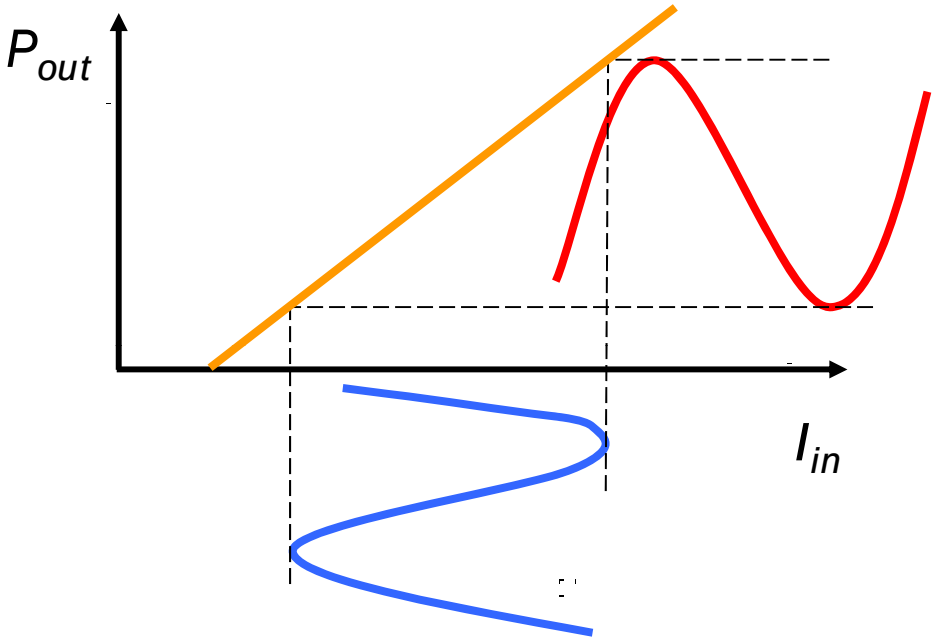
Externally Modulated CATV Transmission



Mach-Zehnder modulator

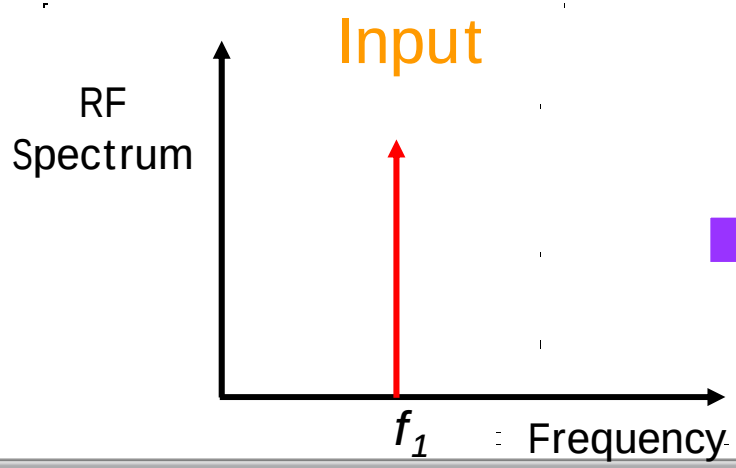


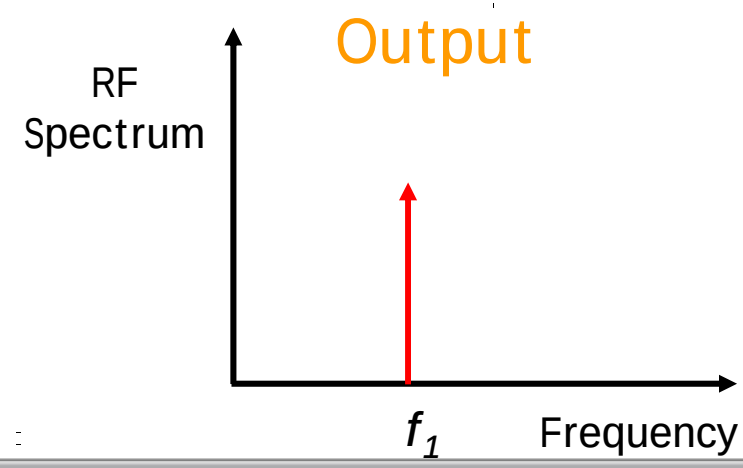
Linear Transmission System



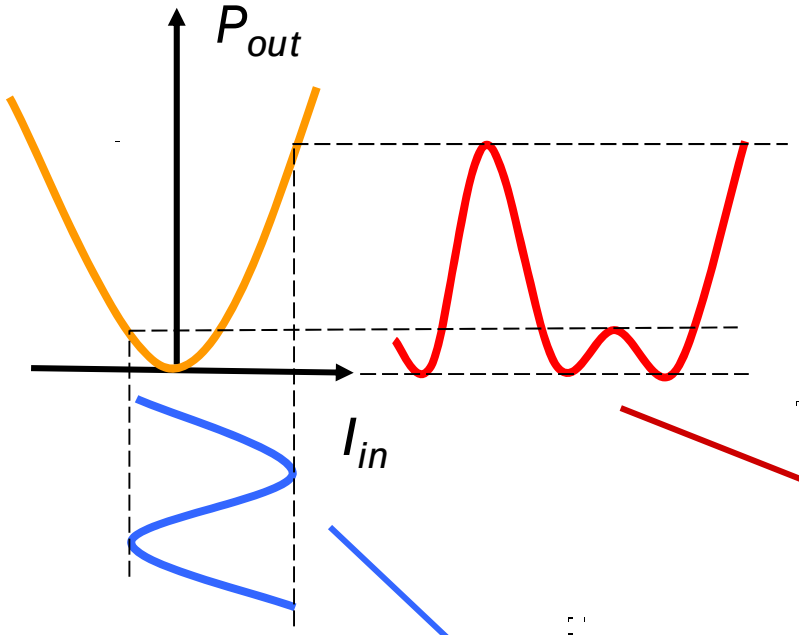
$$I_{in} = a_0 + a_1 \sin(f_1 t)$$

$$P_{out} = A + BI_{in}$$
$$= (A + Ba_0) + Ba_1 \sin(f_1 t)$$





Second Order Harmonic Distortion



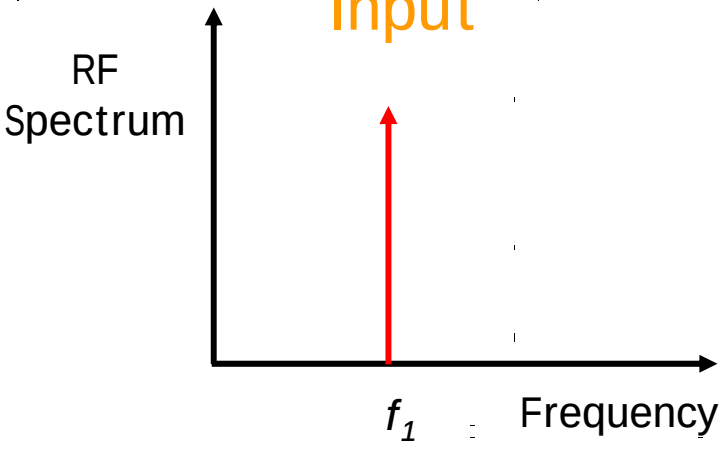
$$I_{in} = a_0 + a_1 \sin(f_1 t)$$

$$P_{out} = C I_{in}^2$$

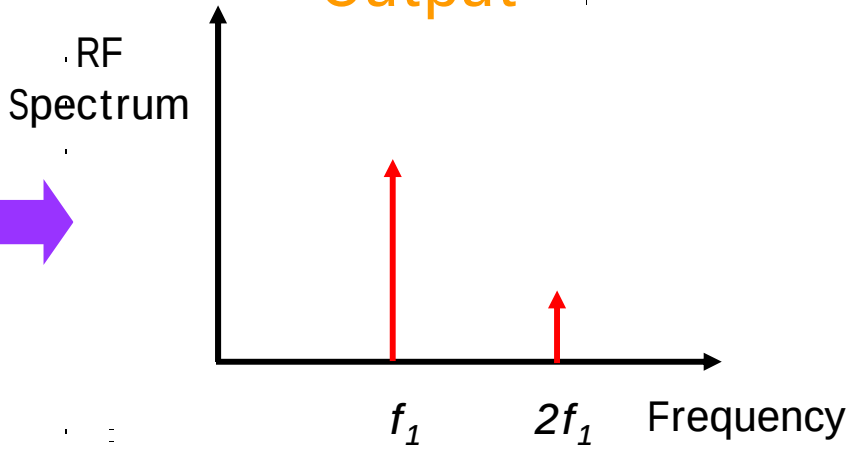
$$= C[a_0 + a_1 \sin(f_1 t)]^2$$

$$= C[a_0^2 + 2a_0 a_1 \sin(f_1 t) + a_1^2 \sin^2(f_1 t)]$$

Input



Output



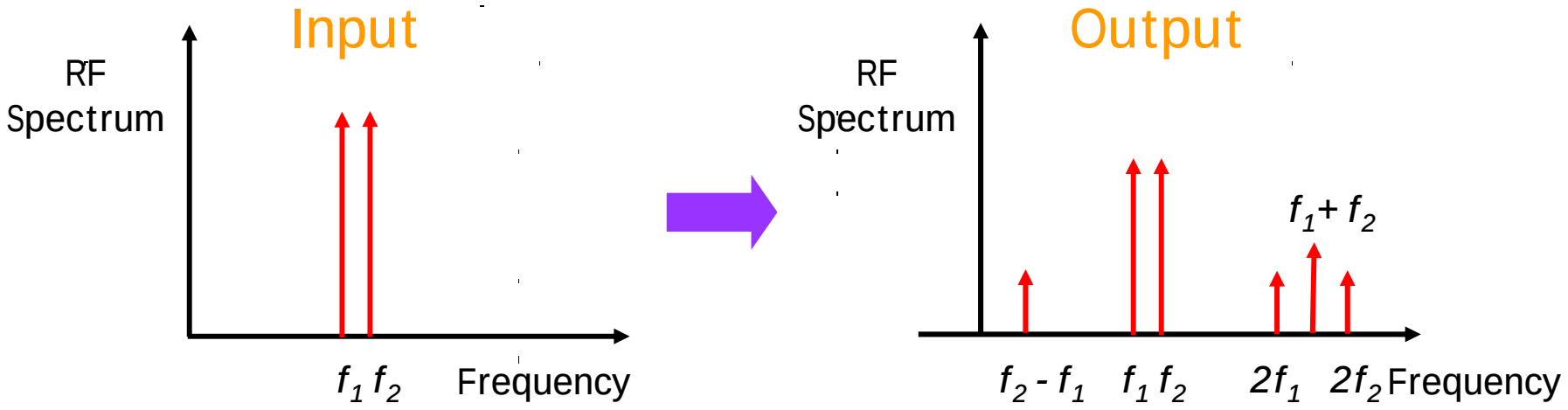
Second Order Intermodulation Distortion

Input: $I_{in} = a_0 + a_1 \sin(f_1 t) + a_2 \sin(f_2 t)$

Output: $P_{out} = C I_{in}^2$

$= C[a_0 + a_1 \sin(f_1 t) + a_2 \sin(f_2 t)]^2$

$= C[a_0^2 + 2a_0 a_1 \sin(f_1 t) + 2a_0 a_2 \sin(f_2 t) + 2a_1 a_2 \sin(f_1 t)\sin(f_2 t) + a_1^2 \sin^2(f_1 t) + a_2^2 \sin^2(f_2 t)]$



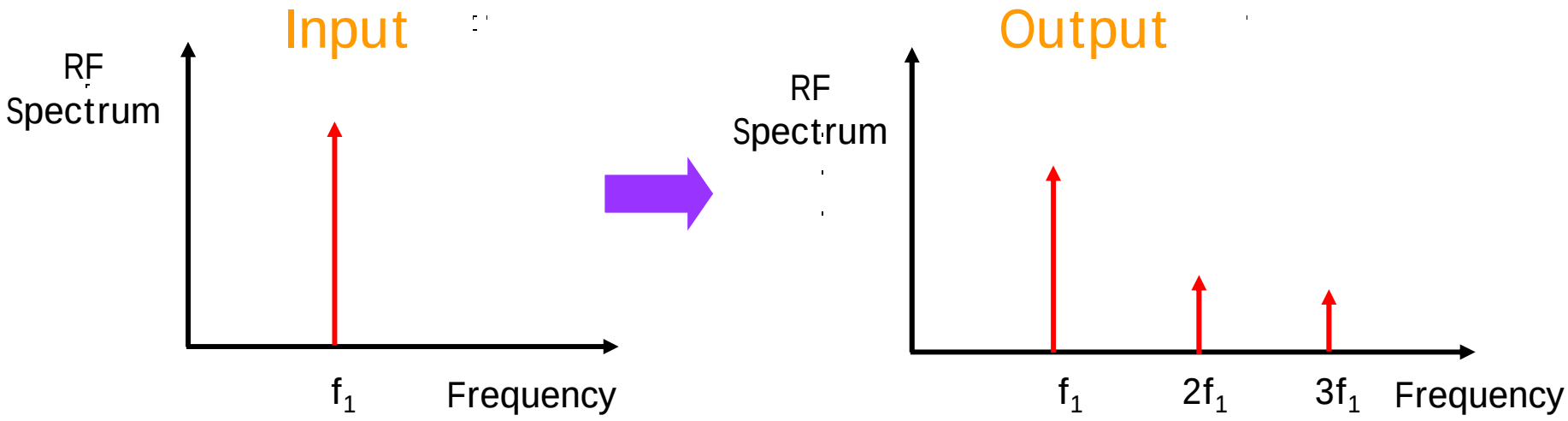
Third Order Harmonic Distortion

$$P_{in} = a_0 + a_1 \sin(f_1 t)$$

$$P_{out} = DP_{in}^{3}$$

$$= D[a_0 + a_1 \sin(f_1 t)]^{3}$$

$$= D[a_0^{3} + 3a_0^{2}a_1 \sin(f_1 t) + 3a_0 a_1^{2} \sin^{2}(f_1 t) + a_1^{3} \sin^{3}(f_1 t)]$$



Third Order Intermodulation Distortion

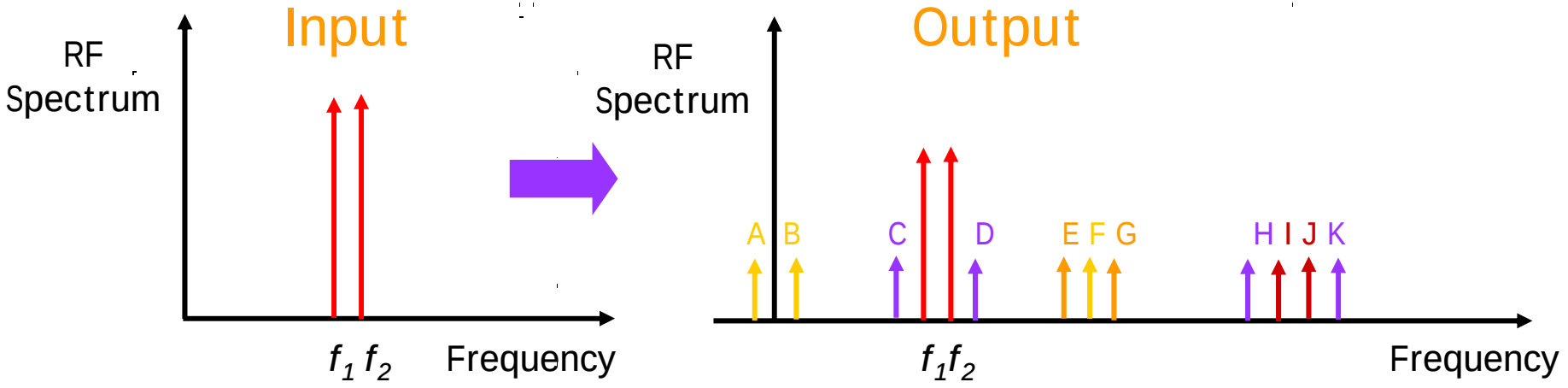
Input: $I_{in} = a_0 + a_1 sin(f_1 t) + a_2 sin(f_2 t)$

Output: $P_{out} = D I_{in}^3 = D[a_0 + a_1 sin(f_1 t) + a_2 sin(f_2 t)]^3$

$= D[a_0^3 + 3a_0^2 a_1 sin(f_1 t) + 3a_0^2 a_2 sin(f_2 t) + 3a_1^2 a_2 sin^2(f_1 t) sin(f_2 t) +$

$3a_0 a_1^2 sin^2(f_1 t) + 3a_0 a_2^2 sin^2(f_2 t) + 3a_1 a_2^2 sin(f_1 t) sin^2(f_2 t) +$

$6a_0 a_1 a_2 sin(f_1 t) sin(f_2 t) + a_1^3 sin^3(f_1 t) + a_2^3 sin^3(f_2 t)]$

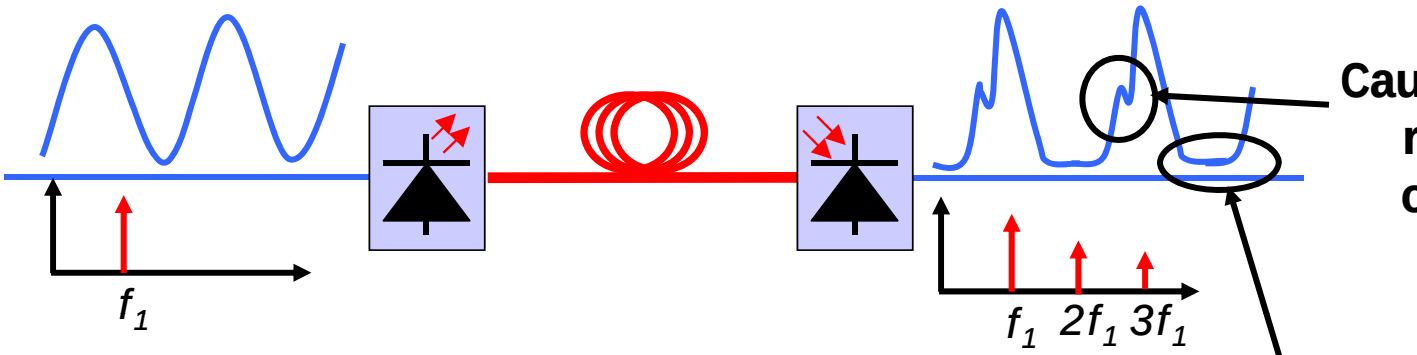


A:f_1-f_2; B:f_2-f_1; C:$2f_1-f_2$; D:$2f_2-f_1$; E:$2f_1$; F:f_2+f_1; G:$2f_2$; H:$3f_1$; I:$2f_1+f_2$; J:$2f_2+f_1$; K:$3f_2$

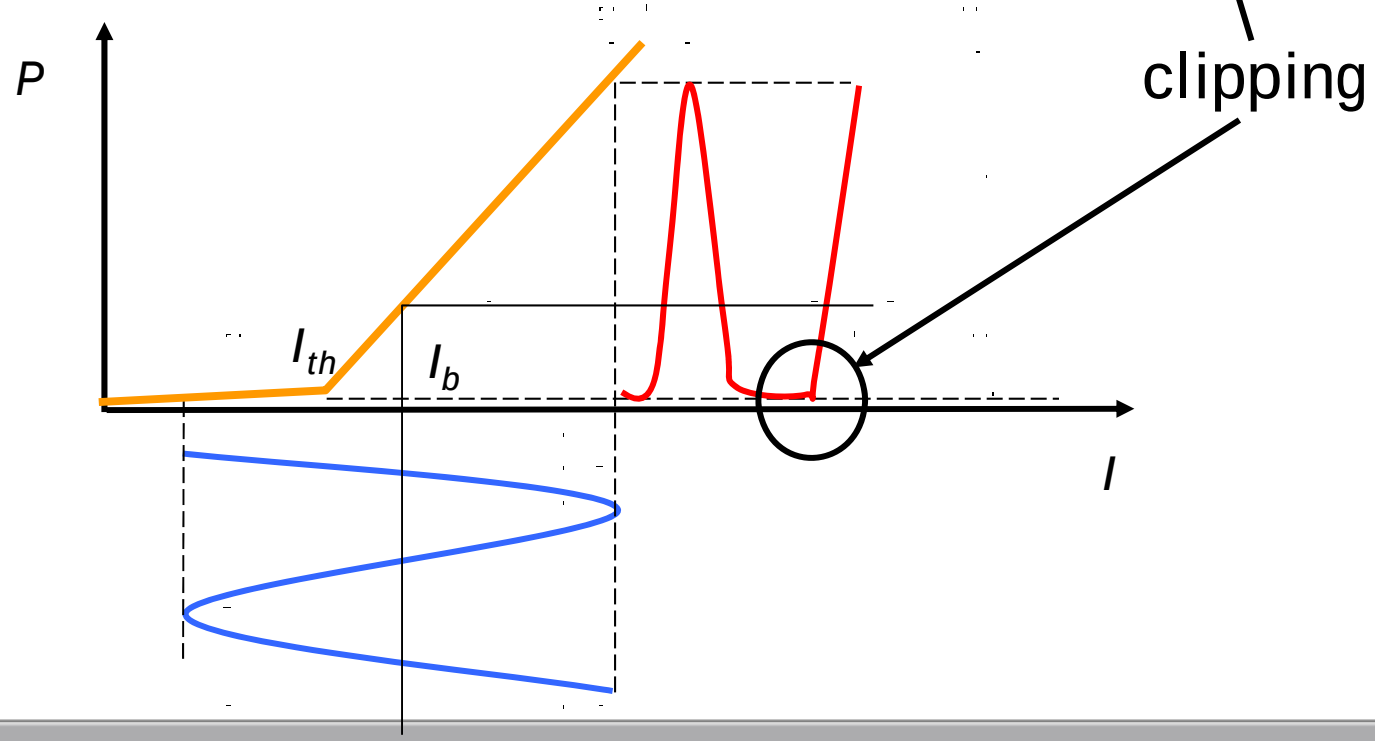
Intermodulation Distortion: Industry Jargon

- 2nd order harmonic and intermodulation distortions are termed "Composite Second Order" or CSO.
- 3rd order harmonic and intermodulation distortions are termed "Composite Triple Beat" or CTB.

Directly Modulated CATV Transmission



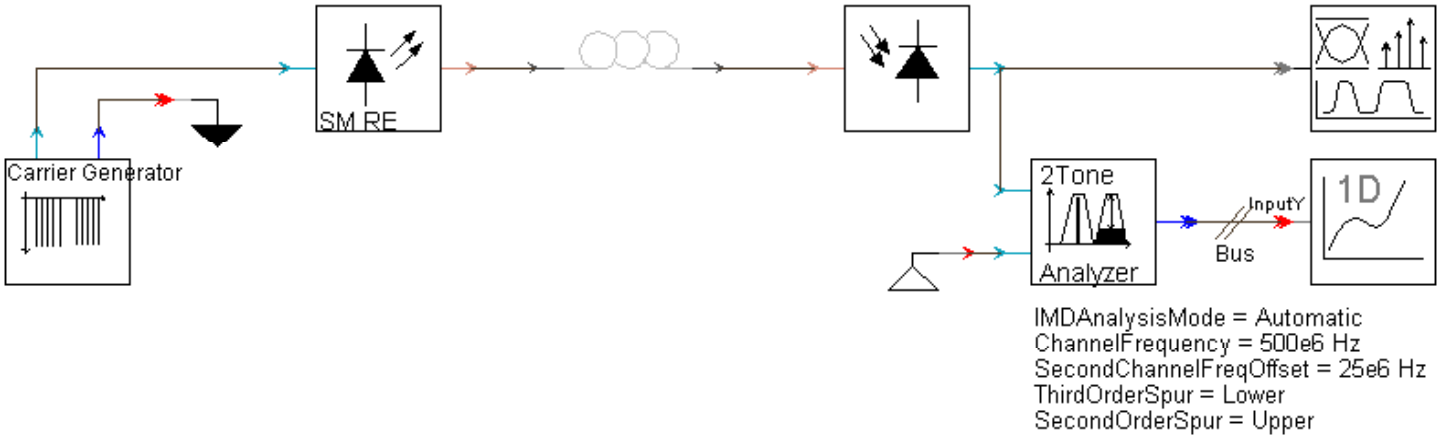
Caused by laser relaxation oscillation



Direct Modulation - Two Tone Setup

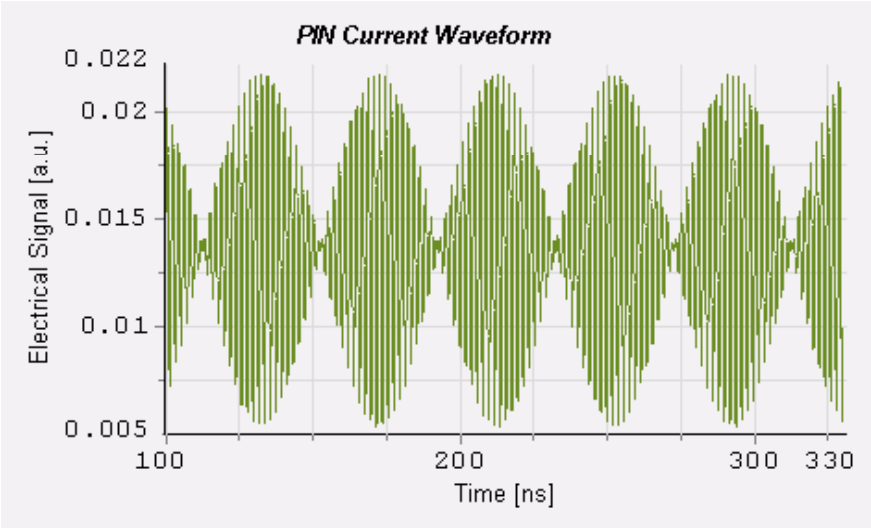
Two Tone Intermodulation Distortion Measurement of Rate Equation Laser 25 MHz channel spacing

This demo shows how to determine the second and third order intermodulation distortion characteristics of a laser using a two-tone method. One carrier at 500 MHz and another carrier at 525 MHz are generated by the carrier generator module for a low modulation index per carrier of 0.15. The listing of drive phases is terminated with a Ground. The carriers feed a LaserSM_RE module, which is fed to a PIN receiver via a fiber. Channel power, SNR, second and third order intermodulation distortions, optical modulation index (OMI) are measured using the TwoTone_Analyzer module.



Experiment to investigate CSO, CTB, Laser Clipping

Direct Modulation - 2nd & 3rd Order Distortion



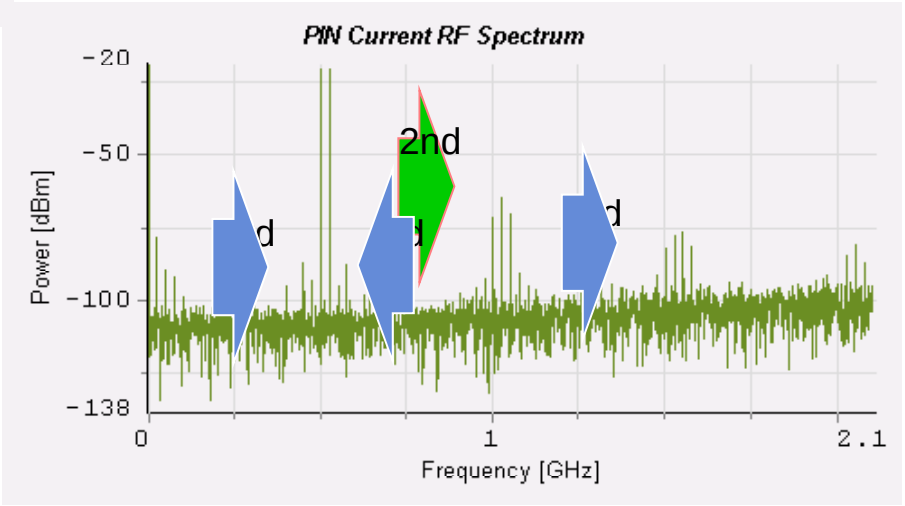
f_1 = 500 MHz

f_2 = 525 MHz

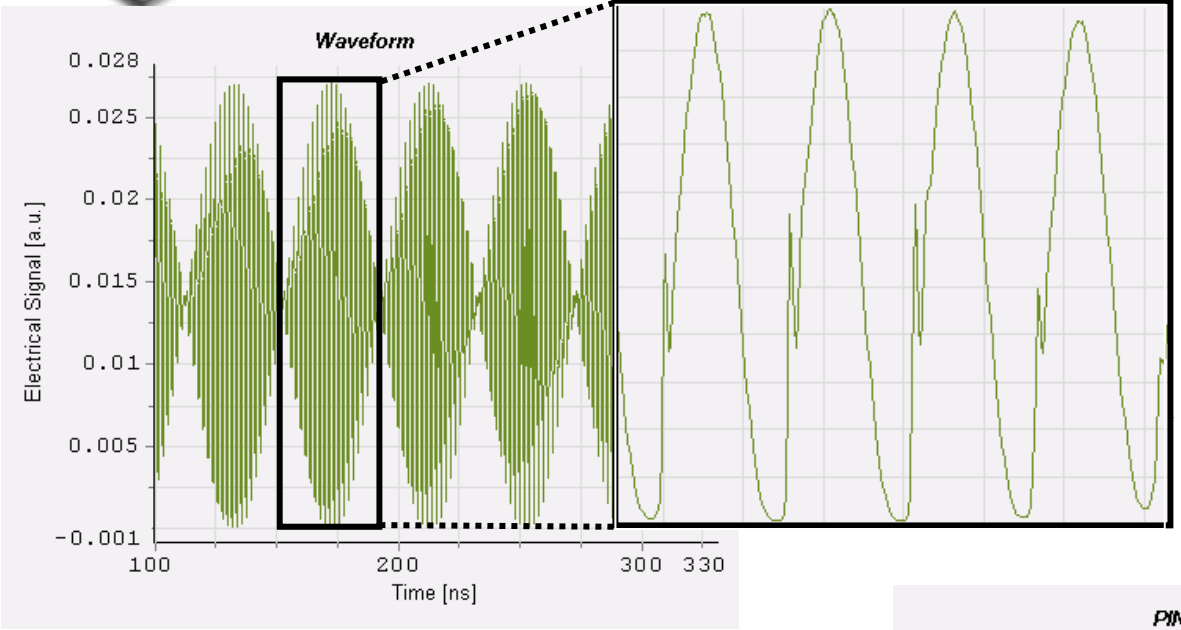
no clipping

m = 0.30

L = 0 km



Direct Modulation – Laser Clipping



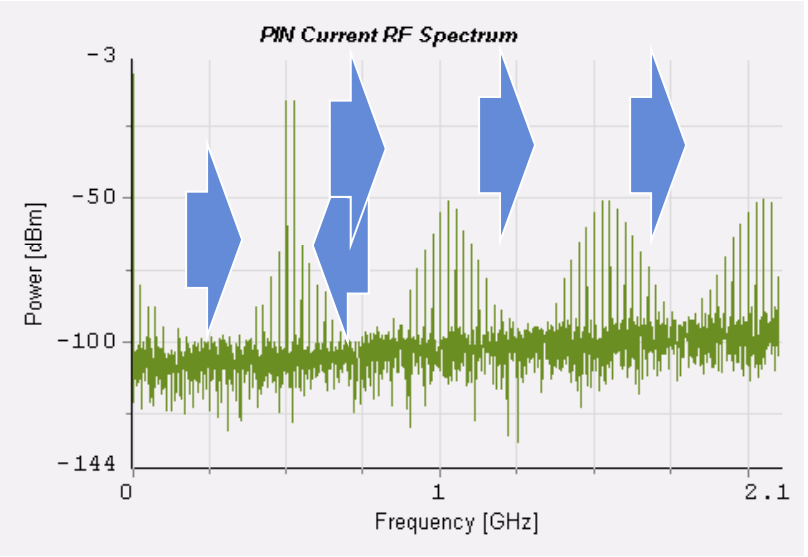
f_1 = 500 MHz

f_2 = 525 MHz

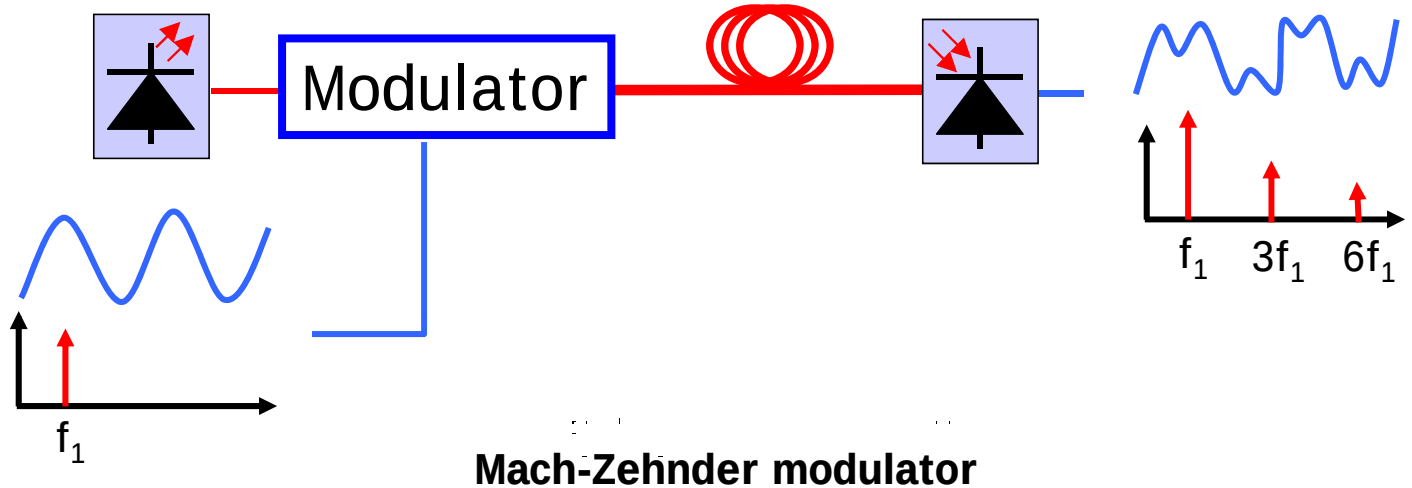
with clipping

m = 0.50

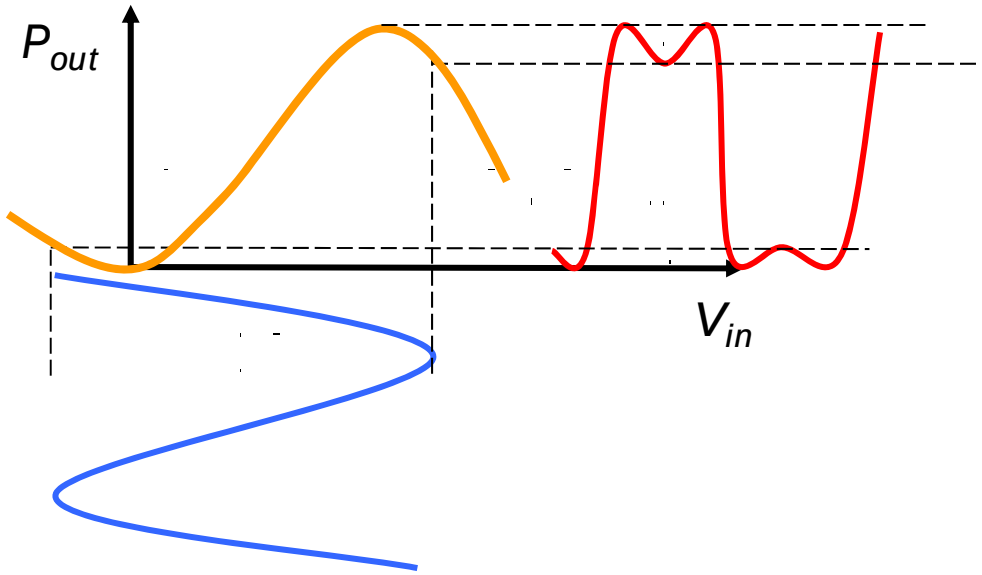
L = 0 km



Externally Modulated CATV Transmission



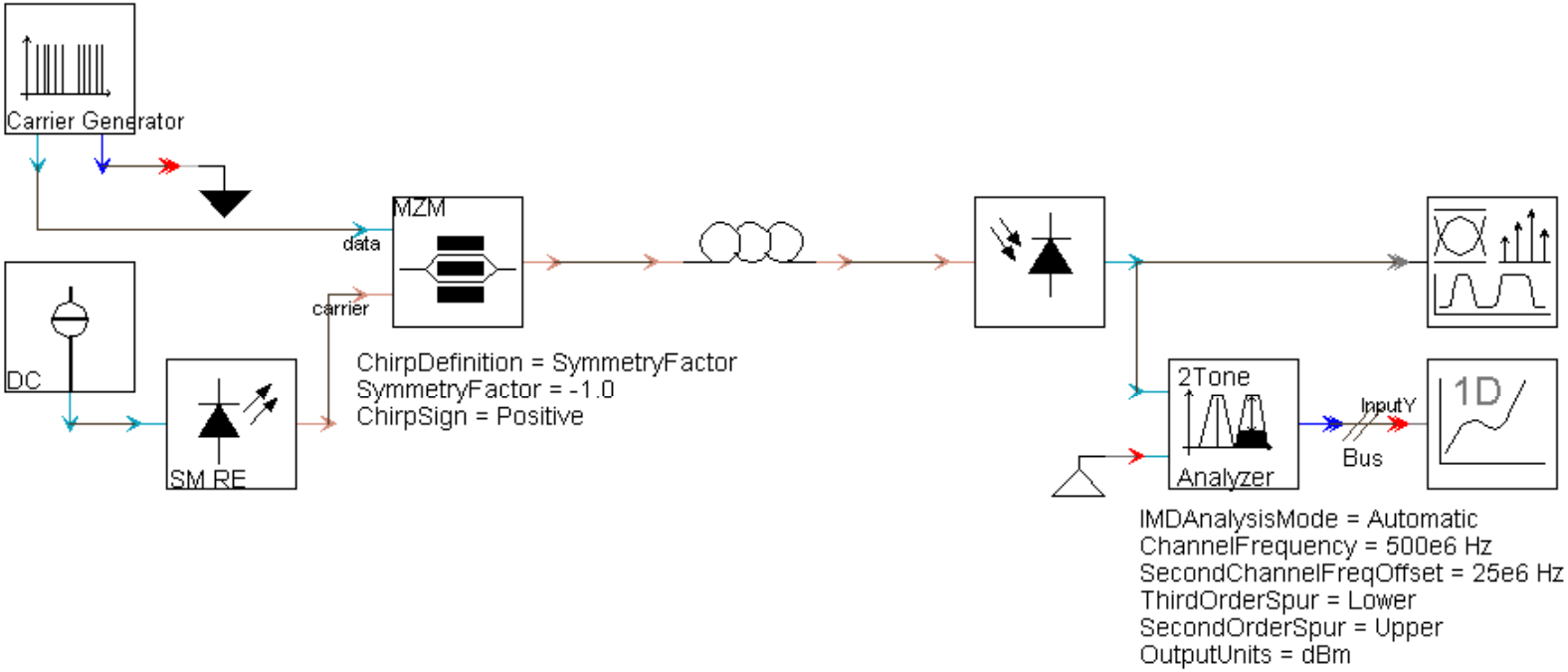
Mach-Zehnder modulator



External Modulation - Two Tone Setup

Two Tone Intermodulation Distortion Measurement of Rate Equation Laser with external modulation (Mach Zehnder)

The problems associated with chirp in DM lasers may be overcome with an external modulator, but at the expense of having a nonlinear optical modulator transfer function. The most common optical modulator is a Mach-Zehnder. Its raised-cosine form of transfer function at the usual bias operating point causes third-order intermodulation distortion. The Mach-Zehnder modulator (ModulatorMZ) models a broad-band modulator and can take into account the optical frequency chirp arising from modulator asymmetry.

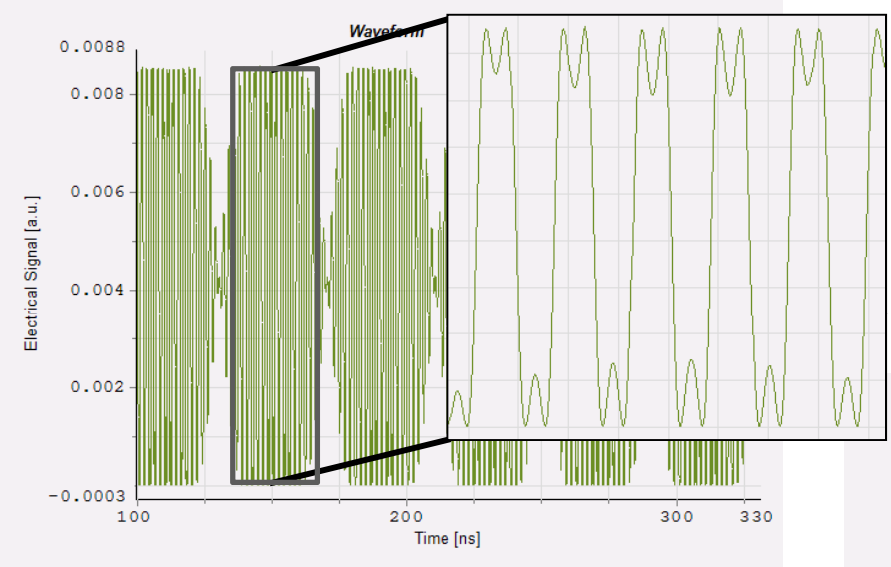


Experiment to investigate CSO, CTB, Inversion Clipping

External Modulation – Inversion Clipping

f_1 = 500 MHz

f_2 = 525 MHz



with inversion clipping

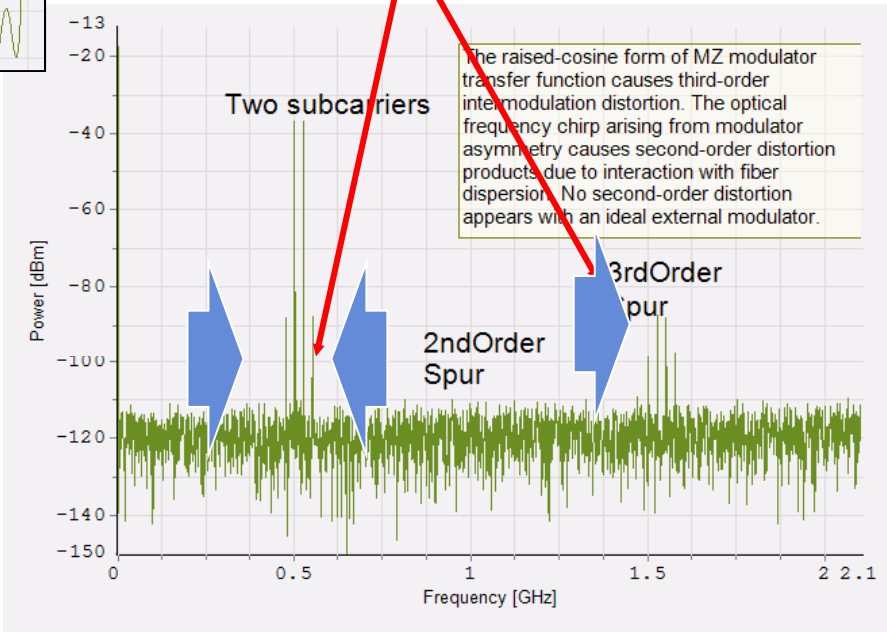
m = 0.7

k = -1.0

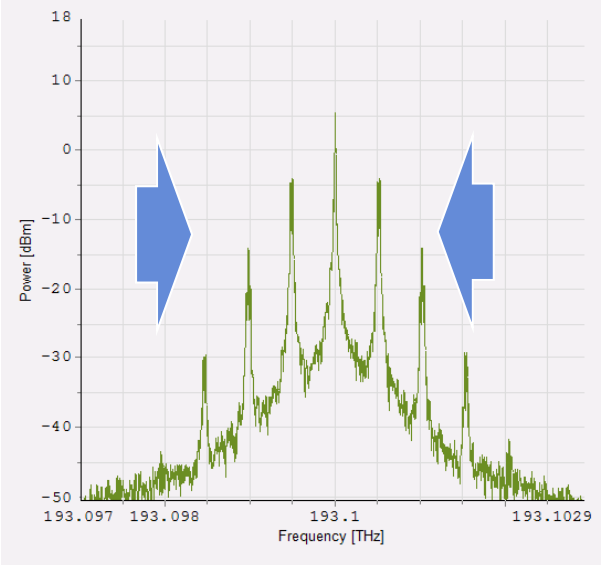
L = 0 km

Symmetrical MZ, no optical chirp

3rd order distortion



External Modulation – 2nd & 3rd Order Distortion



No inversion clipping

m = 0.1

k = 0.8

L = 10 km

Asymmetrical MZ produces optical chirp

f_1 = 500 MHz

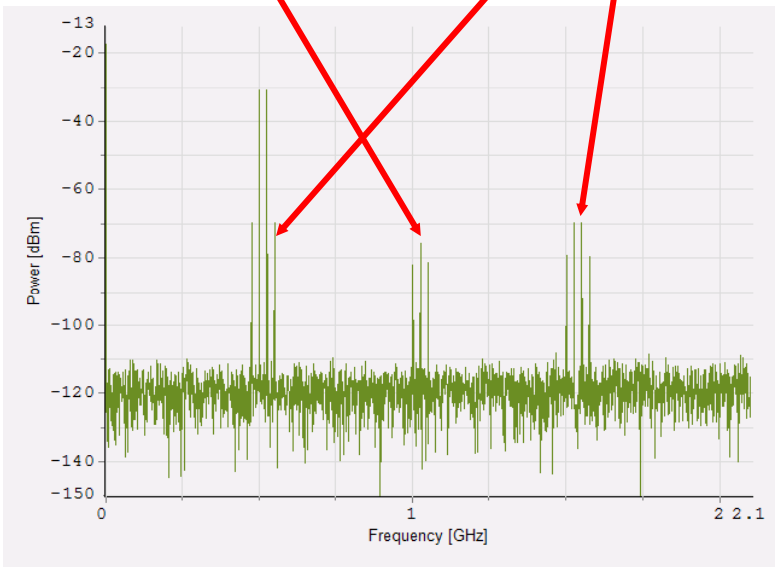
f_2 = 525 MHz

2nd order -

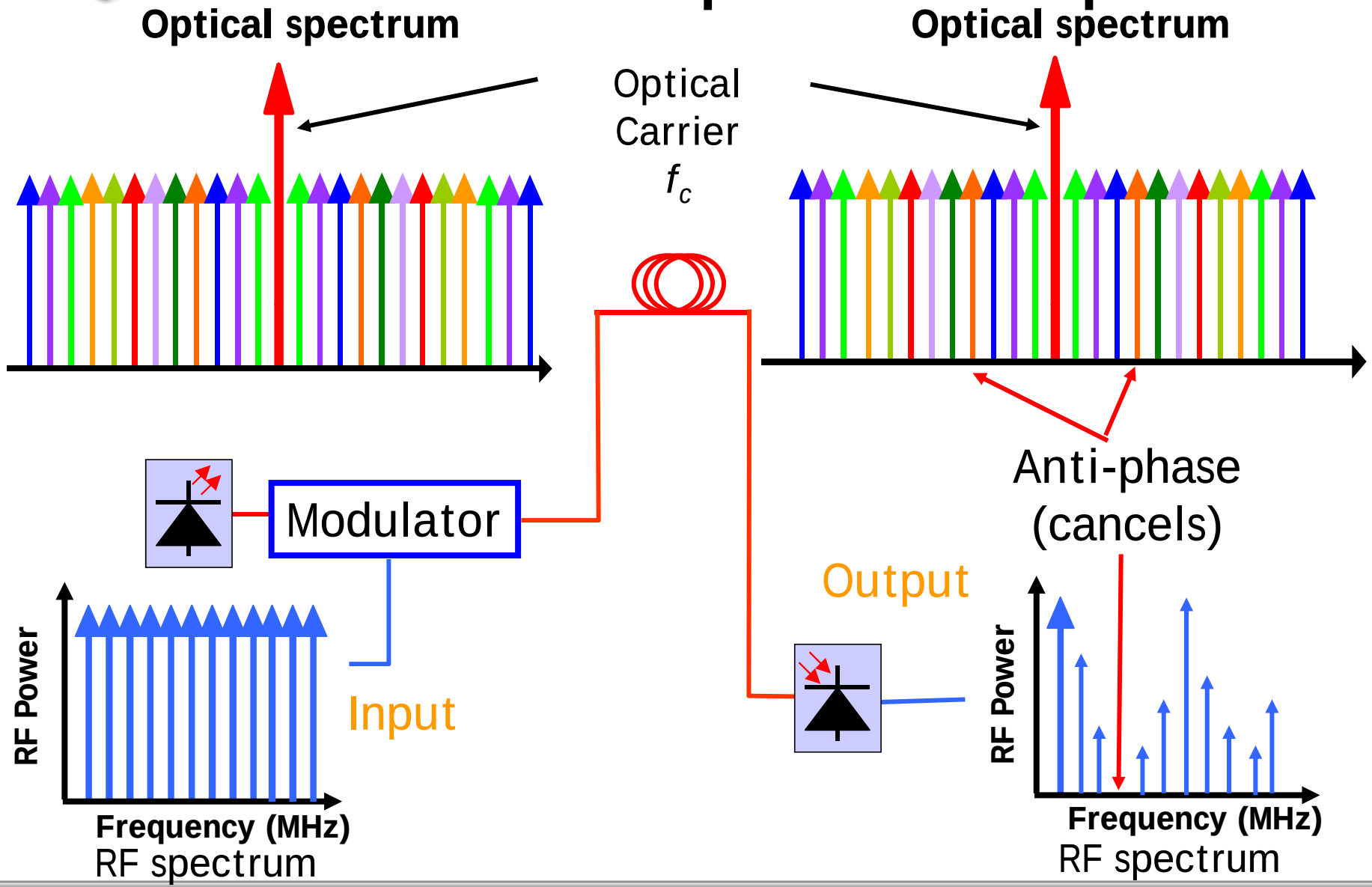
asymmetrical MZ + fiber dispersion

3rd order -

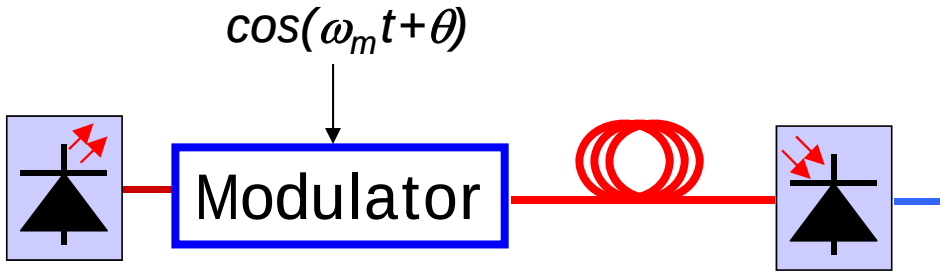
raised cosine MZ characteristic



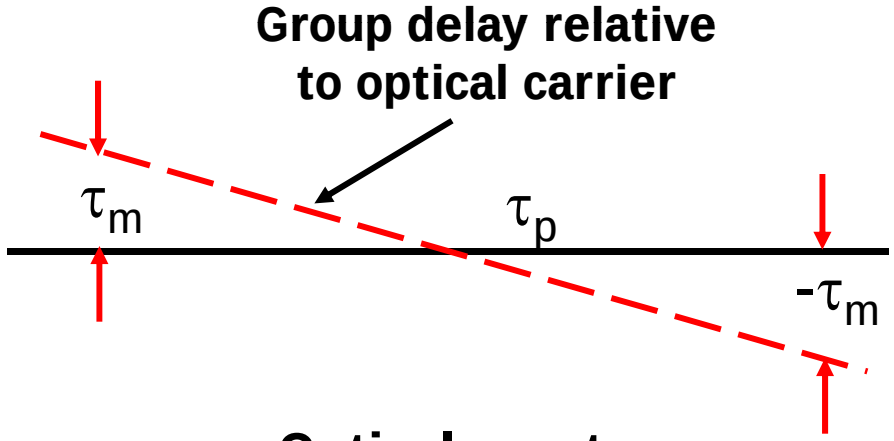
Optical Fiber Impairment



Optical Fiber Impairment



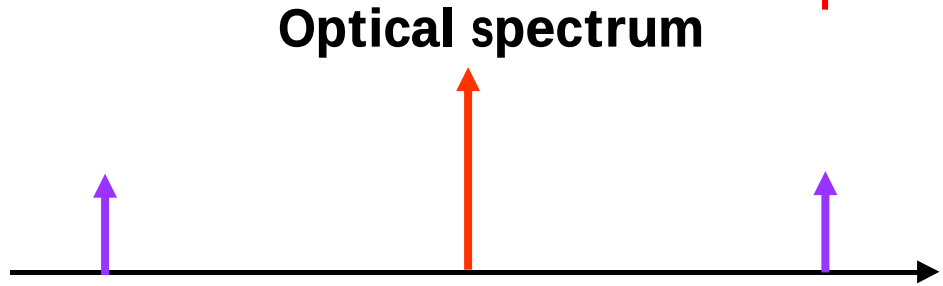
$$R(t) = 1/2\cos(\omega_m(t+\tau_p+\tau_m)+\theta) + 1/2\cos(\omega_m(t+\tau_p-\tau_m)+\theta)$$



$$|r(t)| \propto |\cos(\omega_m \tau_m + \theta)|$$

τ_p: common delay that is introduced to all frequencies by propagation

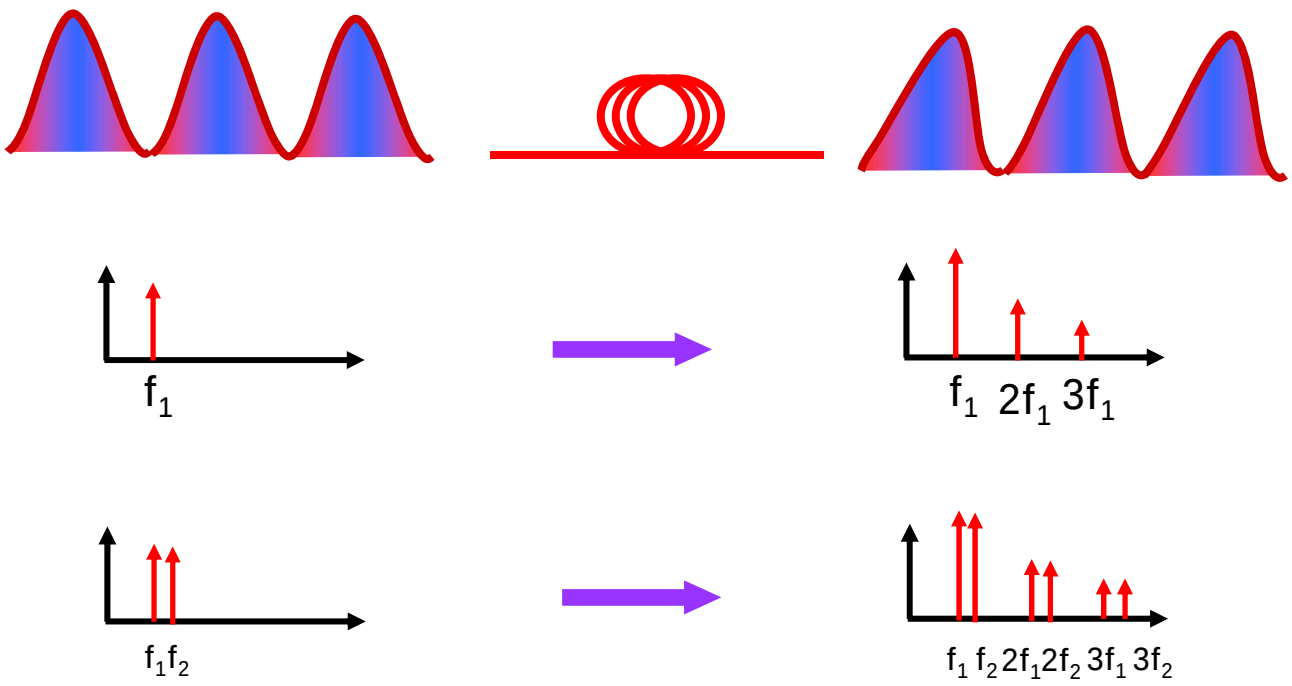
τ_m: differential group delay that is introduced to both subcarrier frequencies by chromatic dispersion



$1/2\cos[(\omega_\lambda - \omega_m)t + \theta]$ $\cos(\omega_\lambda t)$ $1/2\cos[(\omega_\lambda + \omega_m)t + \theta]$

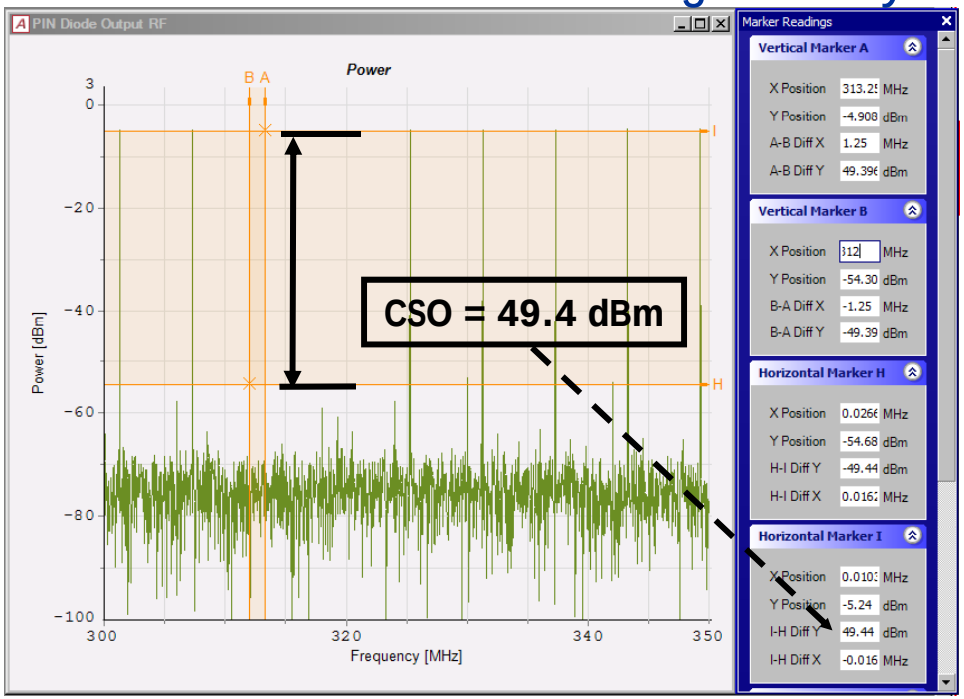
Optical Fiber Impairment

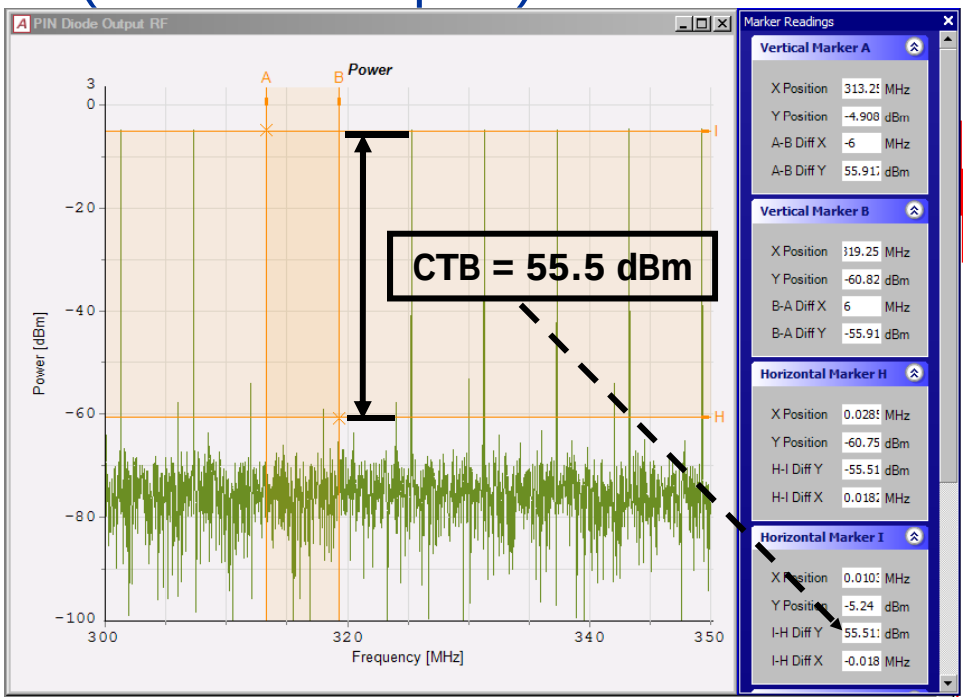
The interaction between optical chirp and fiber dispersion produces second order intermodulation distortion and low values of inband CTB products



System Measurement of CSO and CTB Distortion

For an 80-channel Analog CATV system (NTSC carrier plan)





NTSC carriers:
CSO inter-modulation products are displaced from carriers by +/- 1.25 MHz

- Major components of CTB distortion fall on carrier freqs
- Appropriate carrier must be turned off

Summary

Analog CATV - Technical Challenges

- RF Subcarrier Generation
  - impact of carrier phases
- Direct Modulation
  - slightly nonlinear L-I curve: harmonic distortion & intermodulation products
  - laser chirp, laser clipping
- External Modulation
  - raised-cosine modulation curve: harmonic distortion & intermodulation products
  - chirp (due to asymmetric modulator), inversion clipping
- Fiber propagation
  - effect of dispersion, interaction of chirp and dispersion

Proceed with the *Interactive Learning Module*