Dispersion Elimination and Harmonic Behavior in Optical Networks

Eszter Udvary[1], Tibor Berceli[1], Attila Hilt[2]

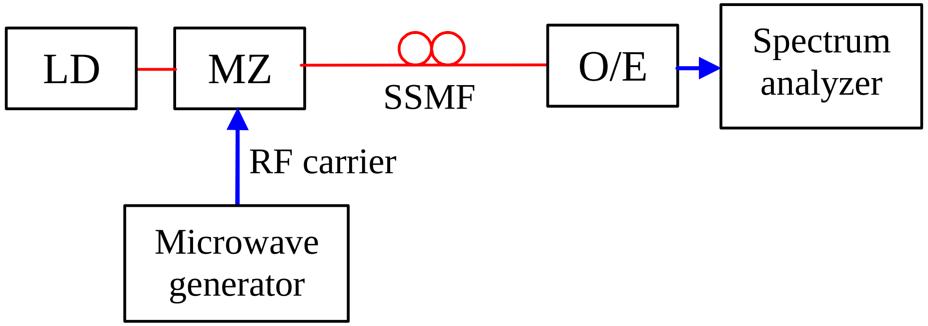
[1] Budapest University of Technology and Economics,
Department of Broadband Infocommunications
[2] Nokia Siemens Networks Hungary Kft.,
Network Planning and Optimisation

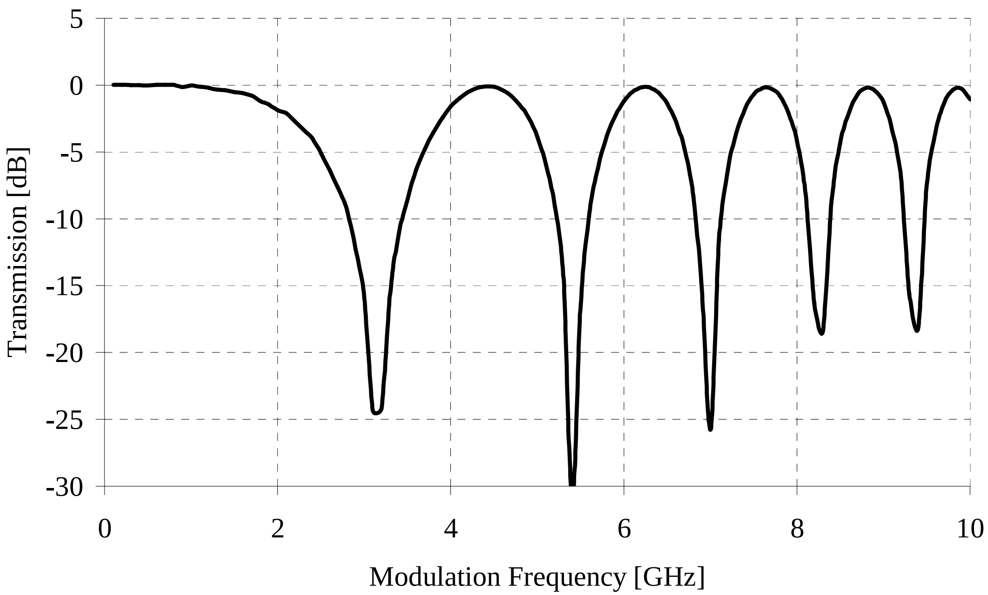
Outline

- Introduction
- Dispersion effect
  - Microwave transmission
  - Baseband digital data
- Fiber nonlinearities
- Harmonics behavior
- SOA compensator
  - Calculation, simulation, measurement
- Conclusion

Chromatic Dispersion Penalty

Microwave transmission





$$H_{link}(f) = \cos\left(\frac{\lambda^2 \cdot D \cdot \pi \cdot f^2 \cdot L}{c}\right)$$

400km, SSMF

1550nm

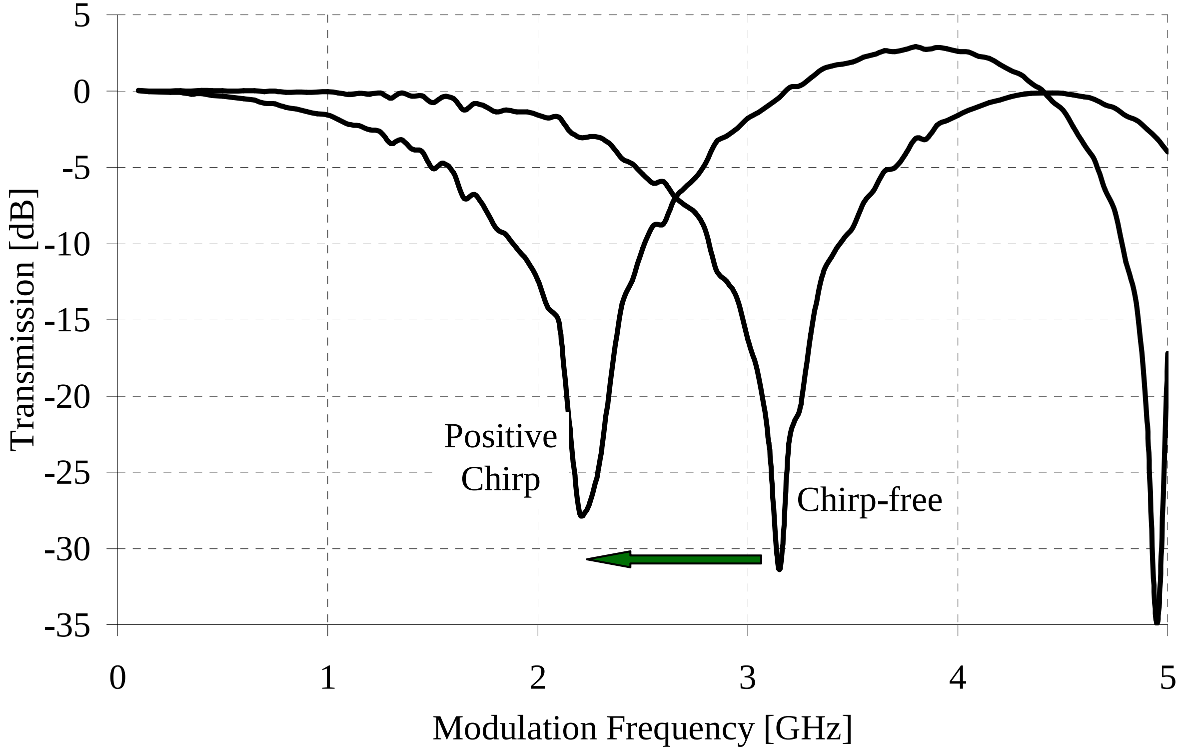
Positive transmitter chirp

Positive chirp:

- Direct modulated laser diodes
- unbalanced external modulator

smaller

- maximum link length
- RF bandwidth

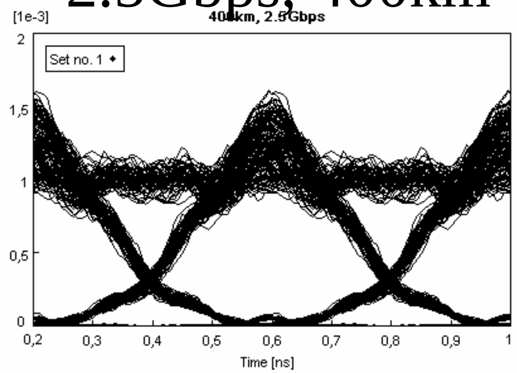


Budapest University of Technology and Economics
Department of Broadband Infocommunication Systems
http://www.mht.bme.hu/~udvary

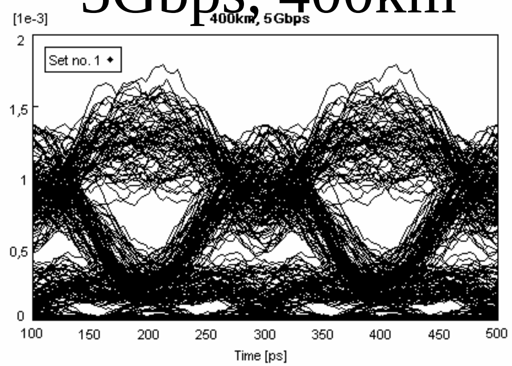
Chromatic Dispersion Penalty

Baseband digital transmission

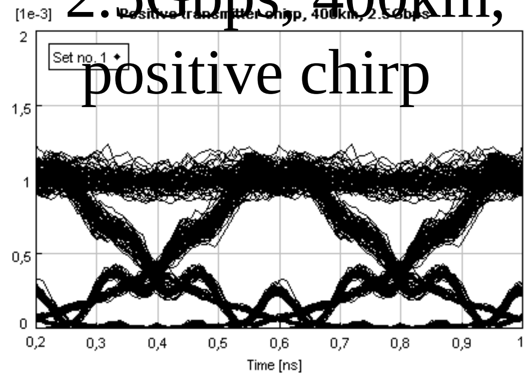
2.5Gbps, 400km

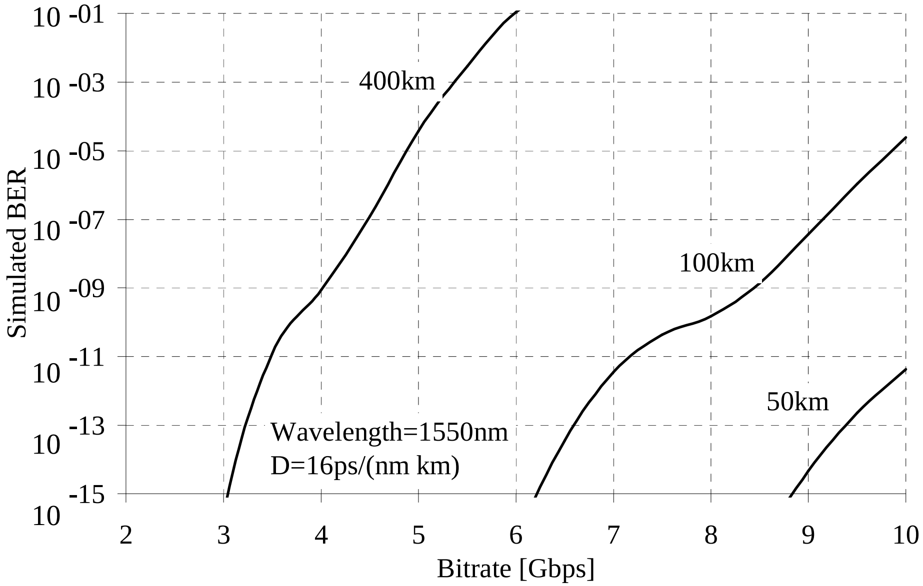


5Gbps, 400km



2.5Gbps, 400km, positive chirp





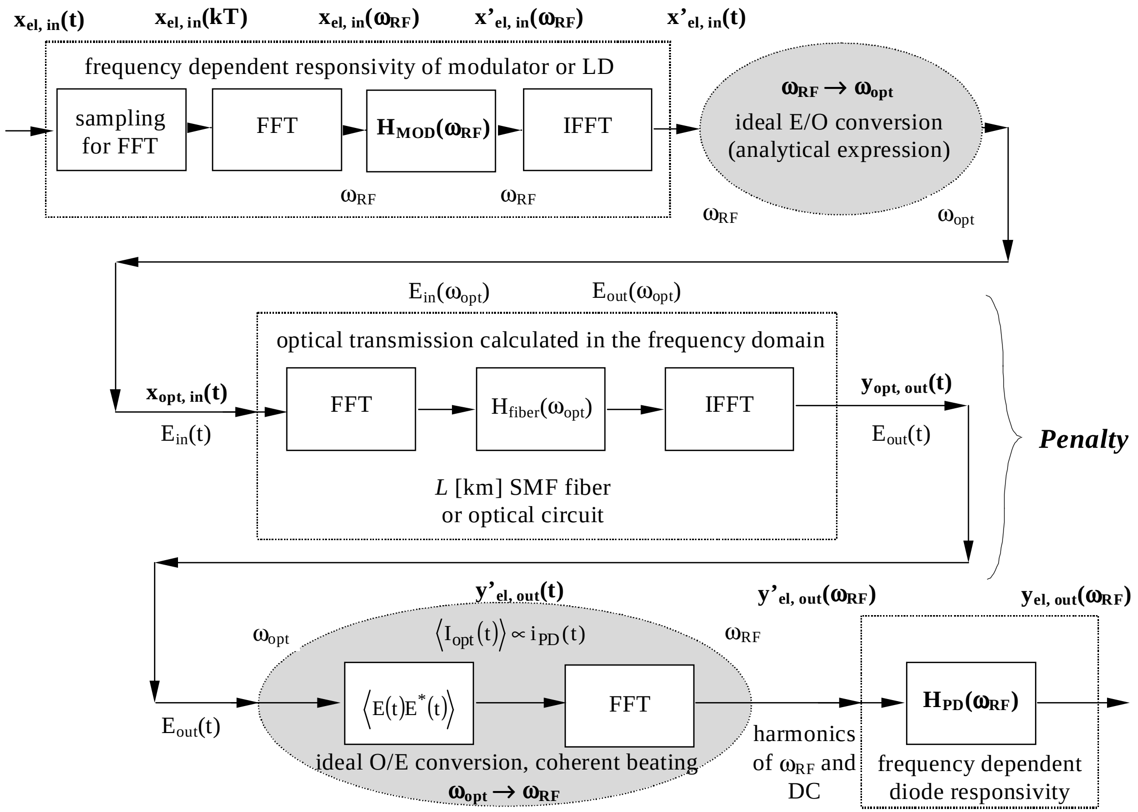
idealized transmission:

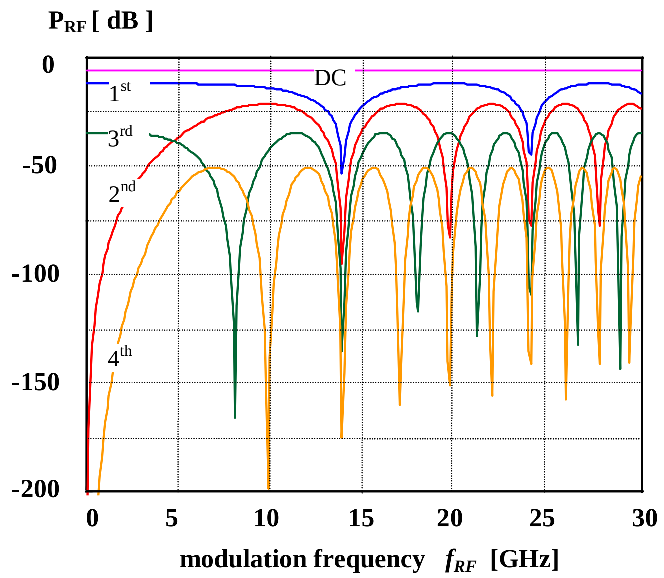
just the chromatic dispersion defects the quality.

In actual real systems:

non-ideal photodetection,
optical attenuation,
noise of optical amplifier,
etc.

Harmonic generation – coherent model

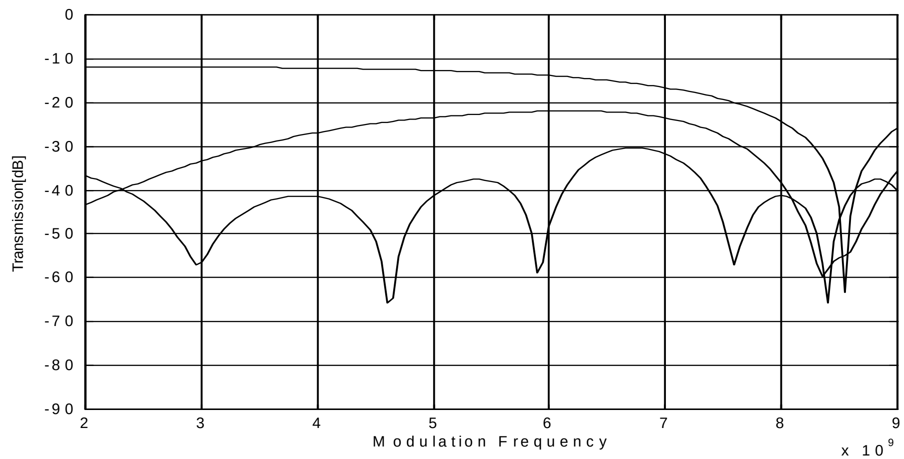




Harmonic behavior

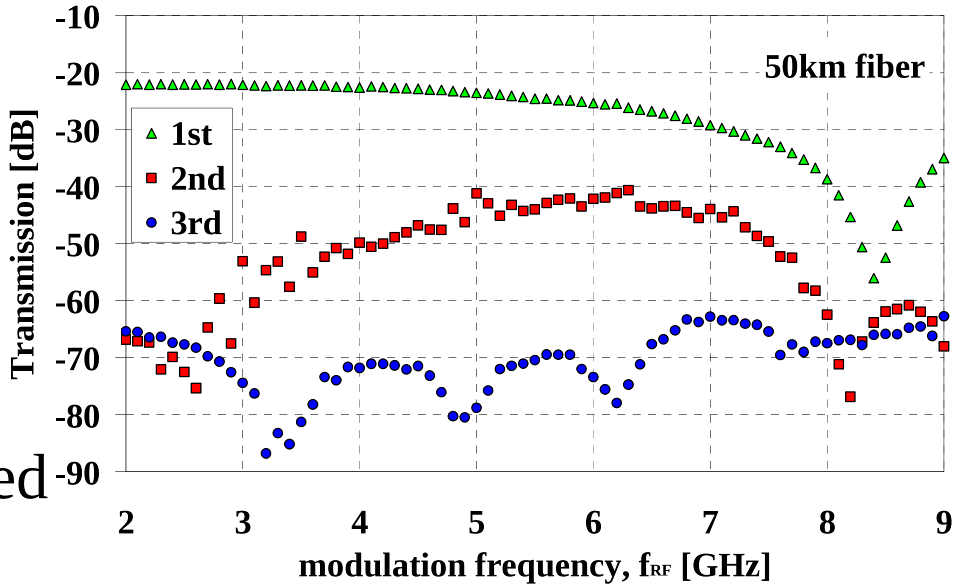
Calculation

the finite spectral purity of the signal source (multitone modulation at the MZM) was considered



Measurement

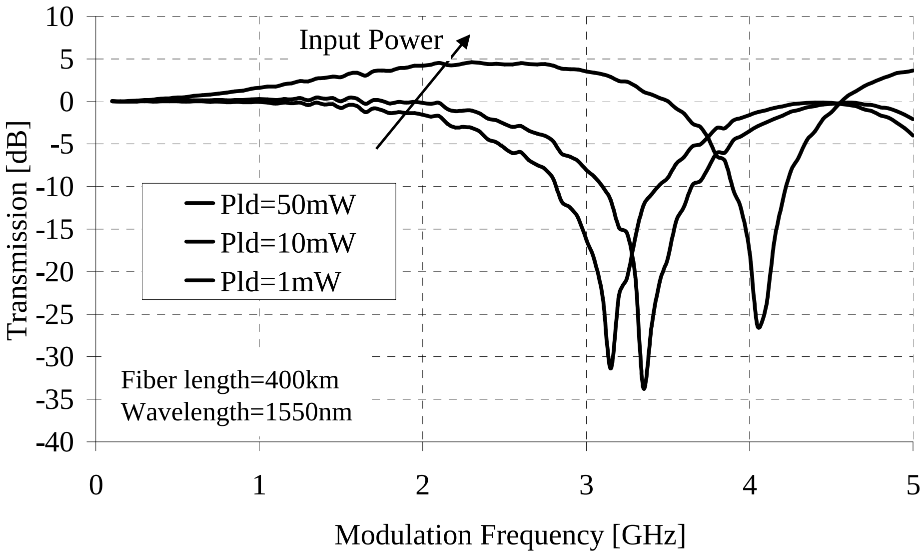
Detected levels of fundamental, second and third harmonics of the optically transmitted MW signals have been measured



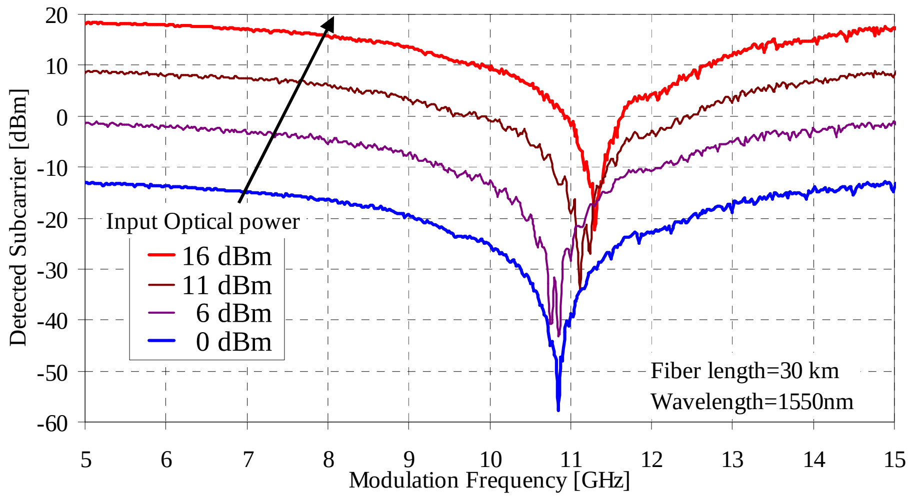
Fiber nonlinearities

high optical intensity => self-phase modulation => modifies the transfer function of the fiber => can compensate modulation suppression caused by dispersion

Simulation



Measurement



SOA compensator - LEF

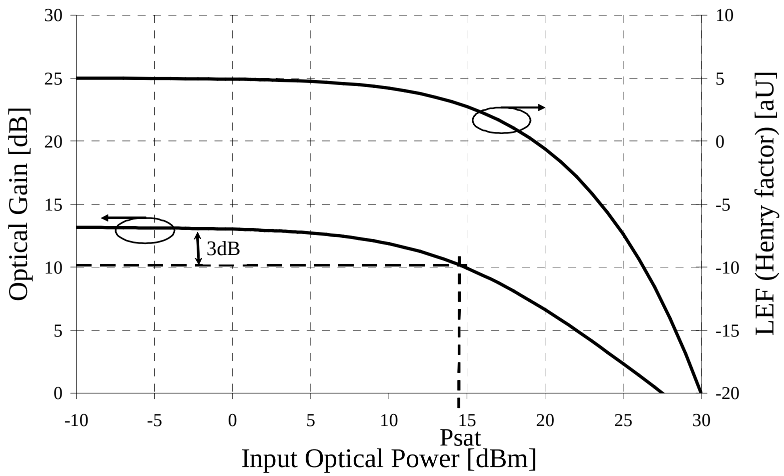
Chirp parameter: Linewidth Enhancement Factor (*LEF*=Henry factor= α factor)
LEF is not a mere constant factor, it is for instance a function of

- bias current
- wavelength
- input optical power
- etc.

LEF=2 … 7 for GaAs, GaInAsP conventional lasers
LEF=1.5 … 2 for quantum well lasers

Saturation in SOA:
input intensity increases => the amplifier gain decreases (dG/dPin<0)
=> **LEF is negative for saturated amplifiers**

$$LEF = LEF_{unsat} \cdot \frac{dG}{dP_{out}} = LEF_{unsat} \cdot \frac{dG / dP_{in}}{1 + (dP_{out} / dP_{in})}$$



SOA dispersion compensator

Saturated SOA => negative chirp

$\Rightarrow$ cancels the positive chirp-parameter of the transmitter

$\Rightarrow$ enhances the transmission distance and operating frequency

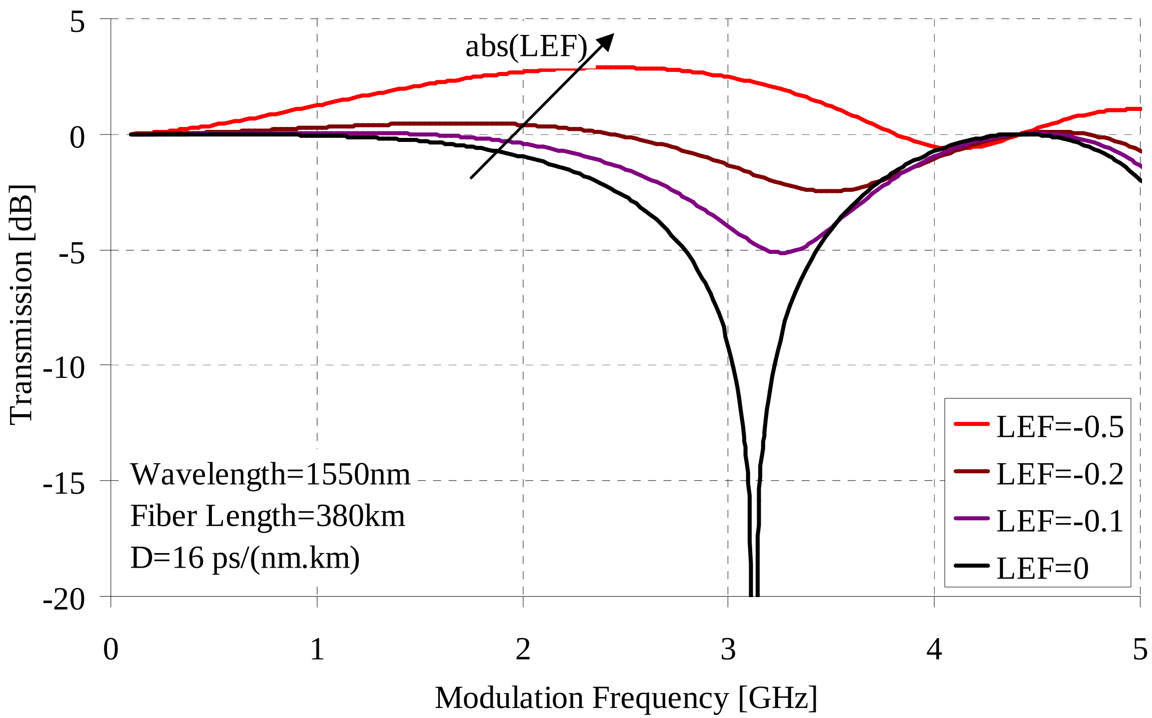
$\Rightarrow$ causes the asymmetrical optical power between sidebands

the RF carrier suppression effect is reduced

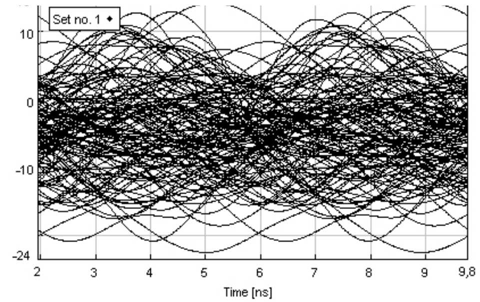
$$H_{SOA+link}(f) = \cos\left(\frac{\lambda^2 \cdot D \cdot \pi \cdot f^2 \cdot L}{c}\right) -$$

$$- LEF \cdot \sin\left(\frac{\lambda^2 \cdot D \cdot \pi \cdot f^2 \cdot L}{c}\right) + j \cdot LEF \cdot \frac{f_c}{f} \cdot \sin\left(\frac{\lambda^2 \cdot D \cdot \pi \cdot f^2 \cdot L}{c}\right)$$

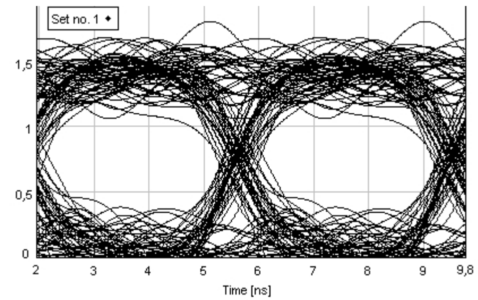
SOA compensator - Simulation



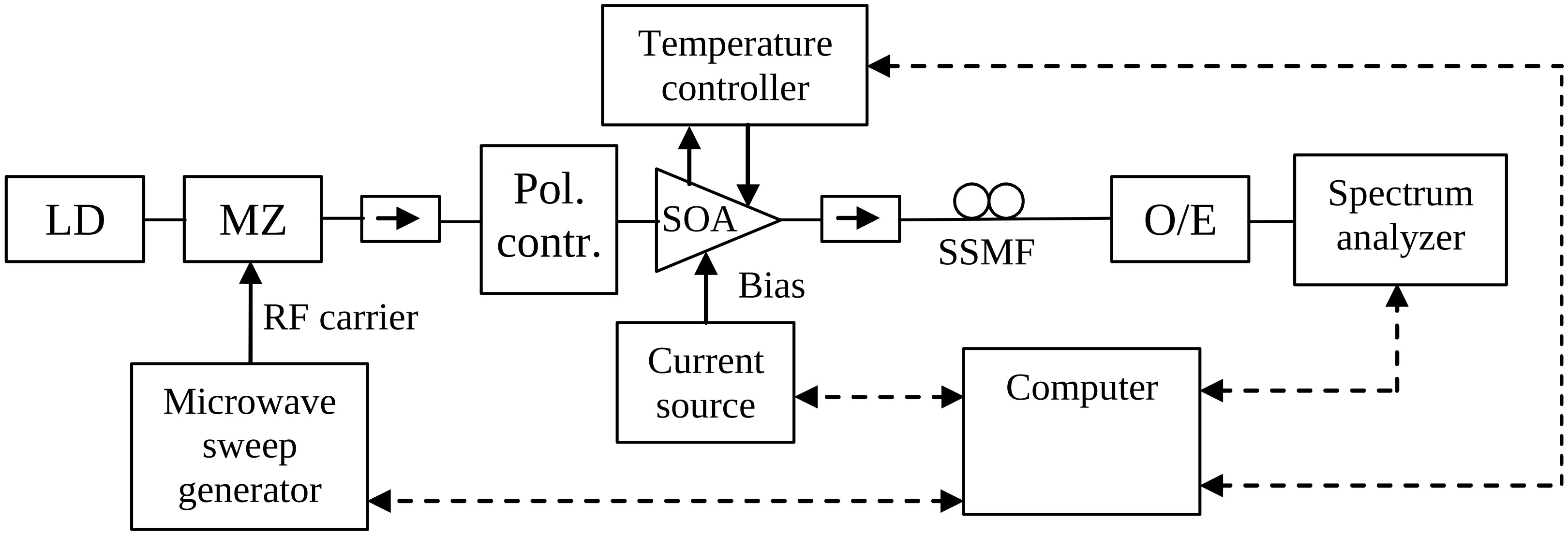
Without SOA compensation



With SOA compensation



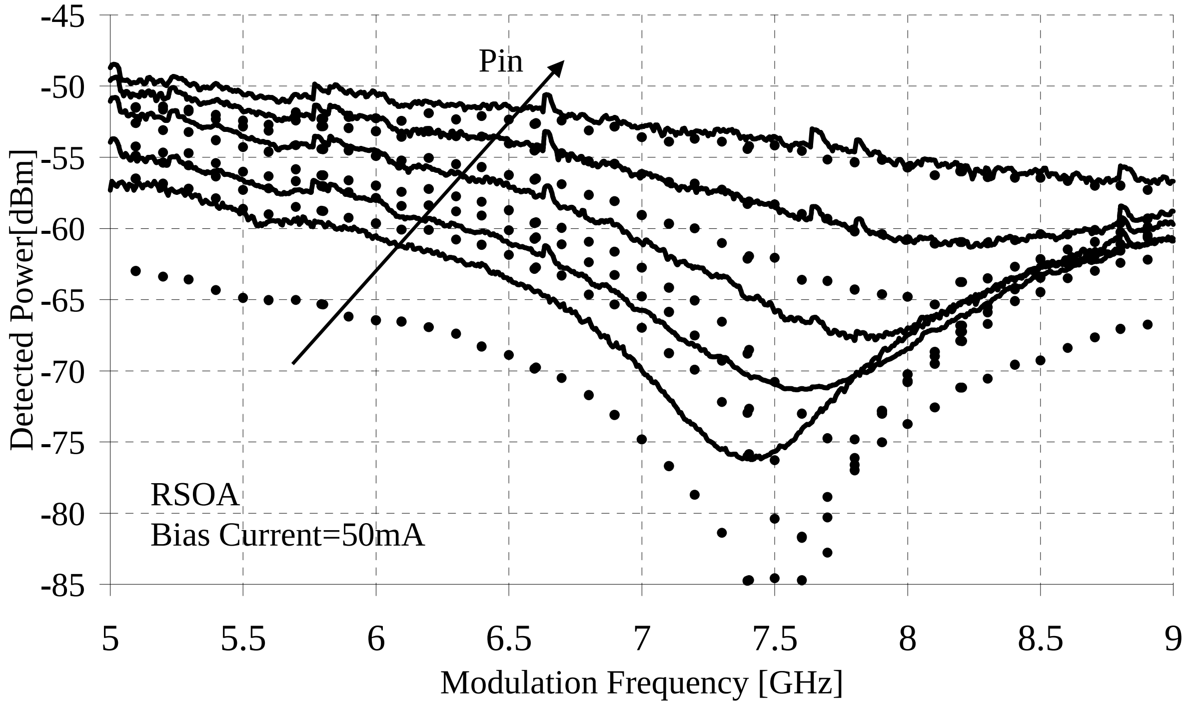
SOA compensator - Measurement



- SOA = semiconductor optical amplifier
- SSMF = standards single mode fiber
- MZ: Mach Zehnder modulator, LD: laser diode
- O/E: opto-electronic converter
- Temperature controller, Polarization controller, Isolator
- Microwave sweep / low noise spectrum analyzer
- Computer

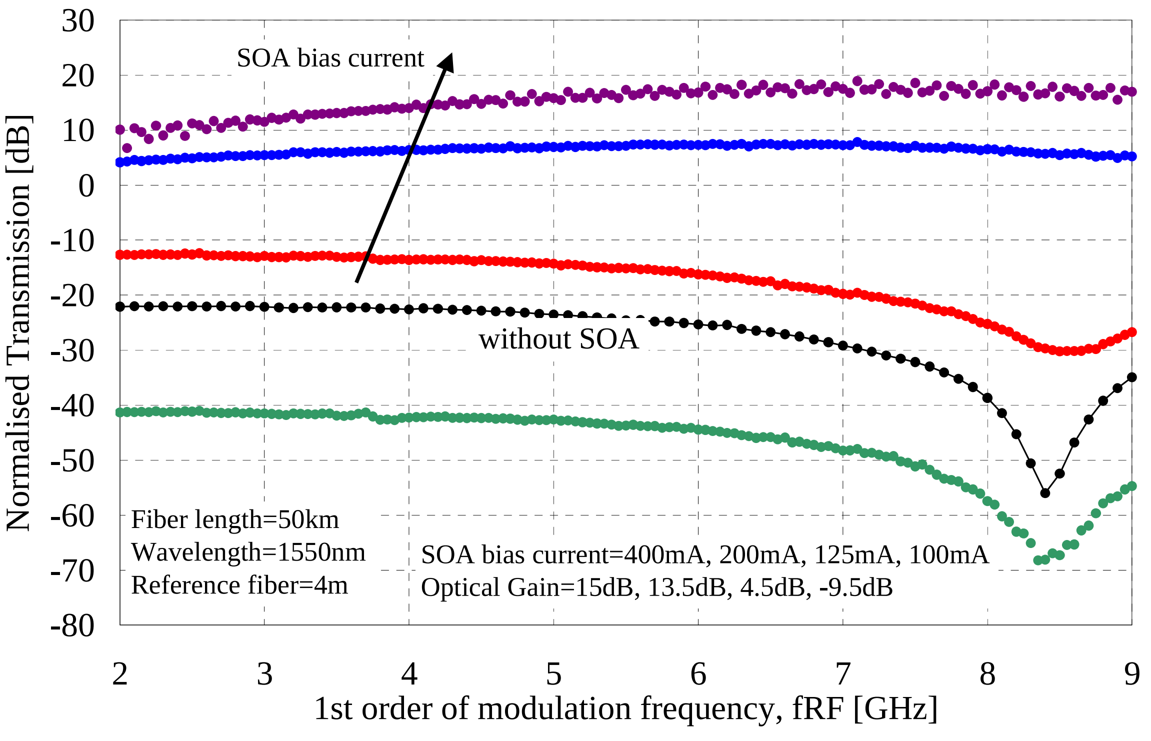
SOA compensator - Measurement

As the optical power increases the SOA goes to the saturation regime, the LEF goes to negative value, hence the frequency notches of the RF response are reduced and shifted to higher modulation frequencies.



SOA compensator - Measurement

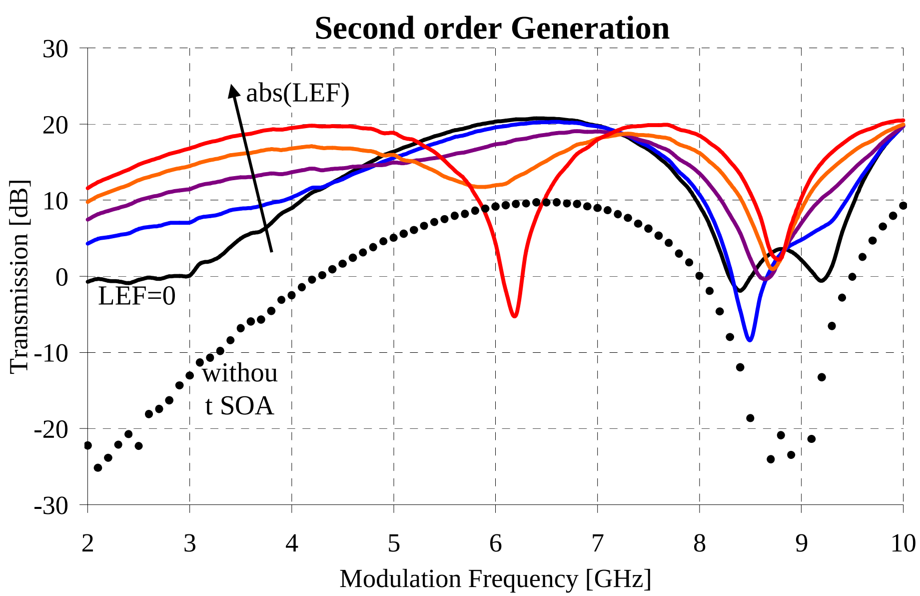
As the SOA bias current (optical gain) increases the frequency notches of the RF response are reduced and shifted to higher modulation frequencies

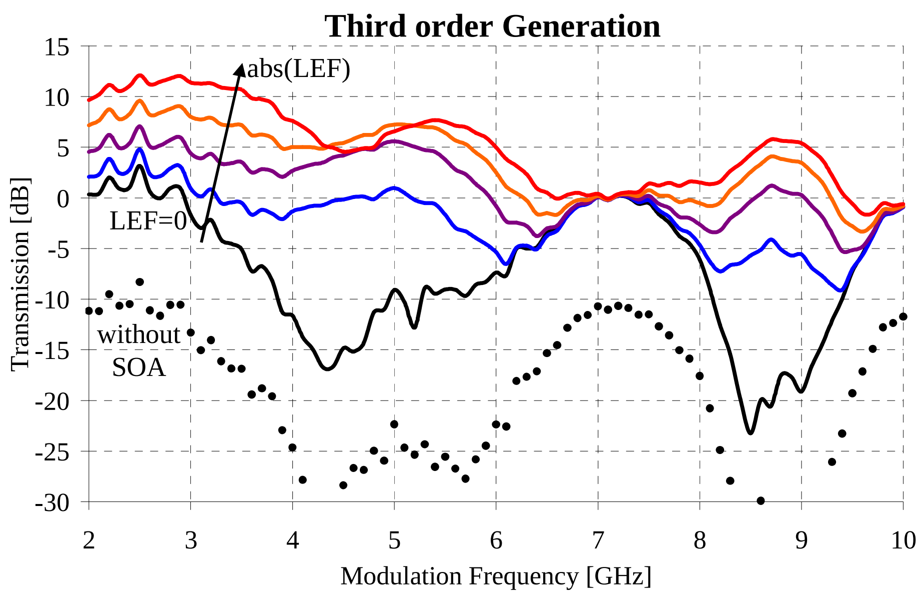


SOA Compensator – nonlinear behavior

Simulation:

As the LEF goes to negative value the depths of second order harmonic rejections are not reduced significantly, but their frequencies are shifted. However the rejections of third order harmonic are eliminated.

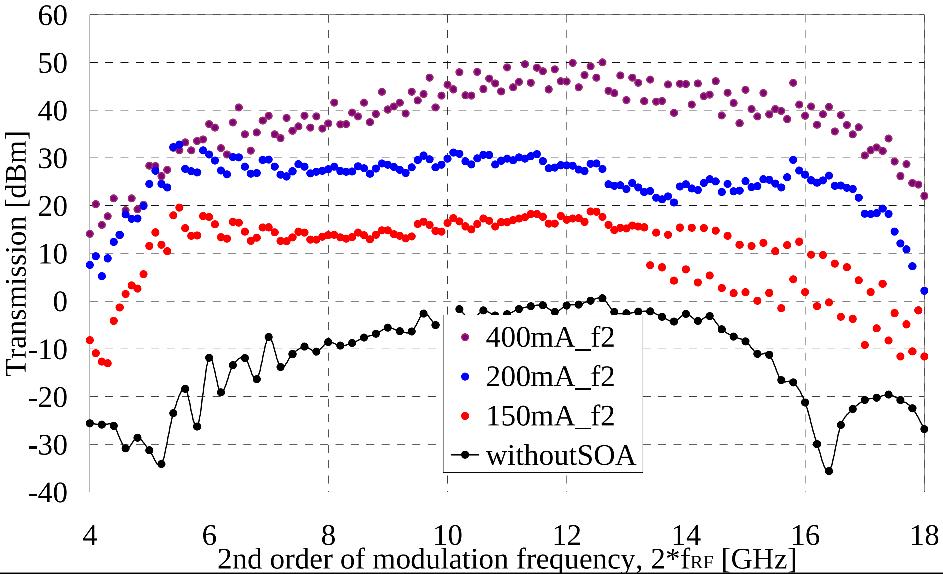


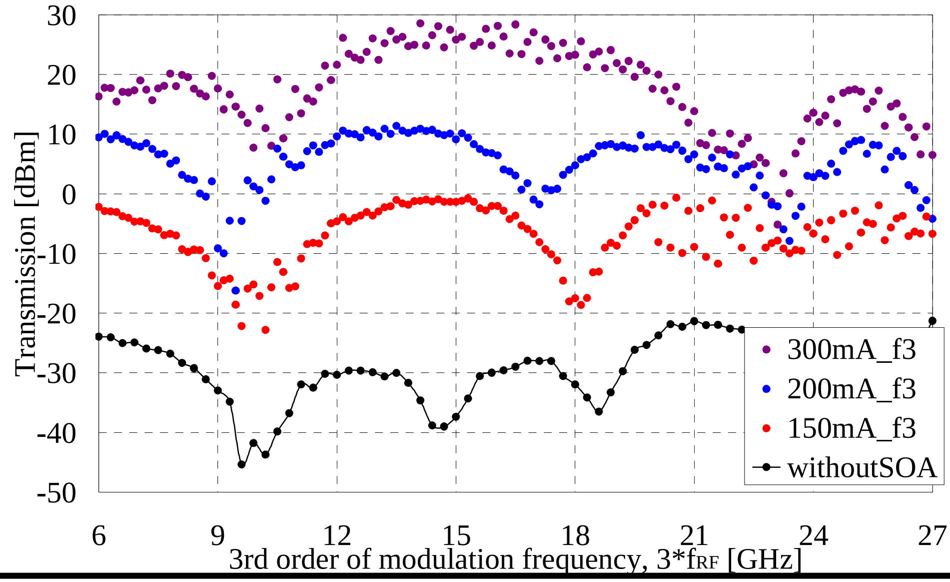


SOA Compensator – nonlinear behavior

Measurement: As the SOA bias current (optical gain) increases

- The third order product increases and the frequency notches of the third order harmonic response are reduced and shifted to higher frequencies
- the form of second order response does not change significantly, the level of the signal increases, because of the optical gain.





Conclusions

- Dispersion effect
  - Microwave transmission
  - Baseband digital data
- Fiber nonlinearities
- Harmonic generation
- SOA
  - Calculation, simulation, measurement
  - Significant reduction of the dispersion-induced effect
  - Harmonic generation