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Analog Application using $LiNbO_3$ modulators and matching components

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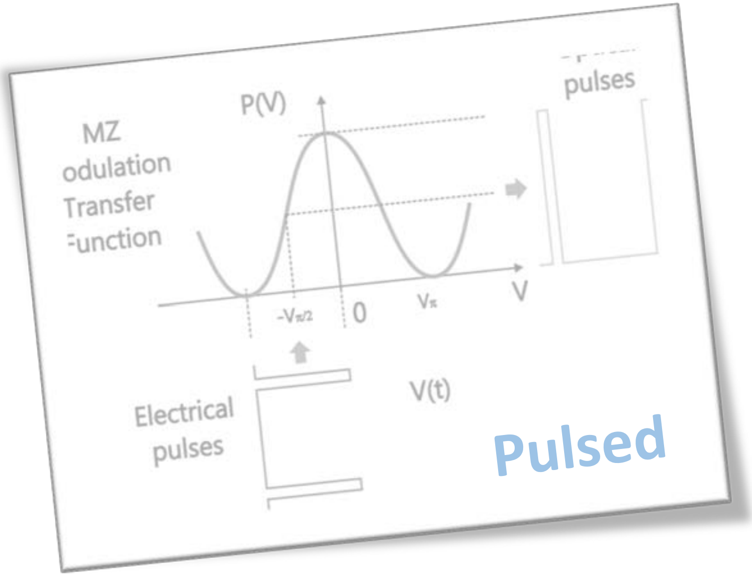
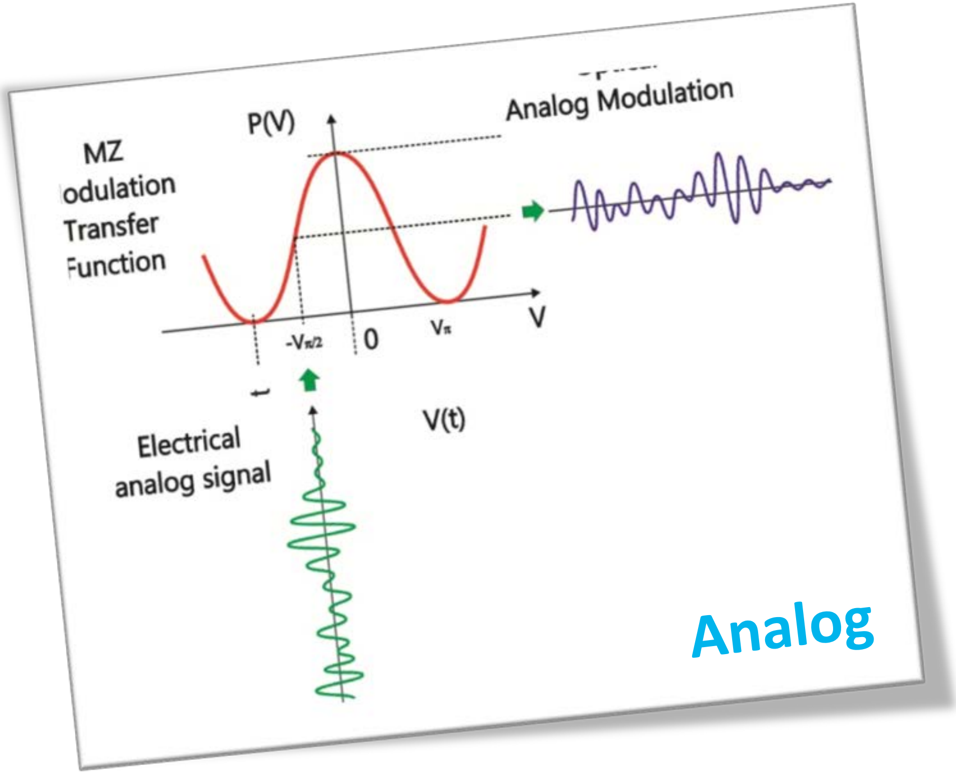
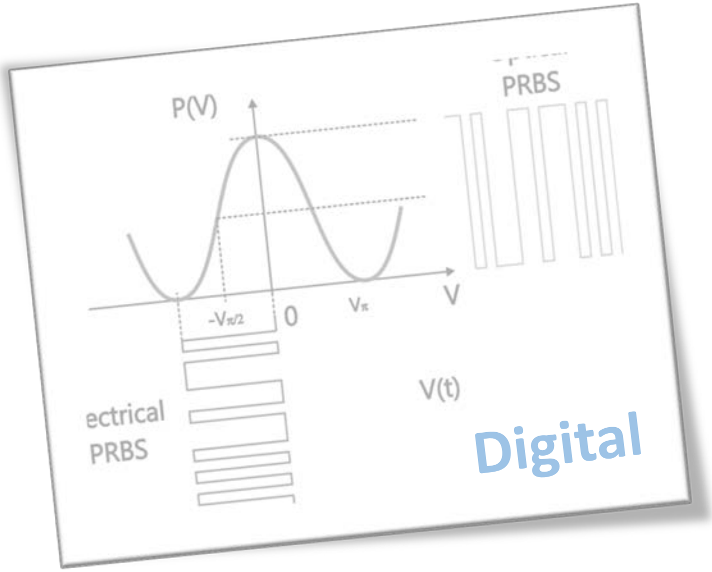
Main modulation formats of Mach-Zehnder Modulators (MZM)







Introduction

iXBlue Photonics develops and produces:

- Analog optical $LiNbO_3$ modulators showing reduced 2nd harmonic distortion.
- High gain and Broadband GaAs MMIC driver amplifiers.
- Dither free modulator bias controller.

The **Photline MXAN** optical analog modulators series are dedicated to high performances analog application and microwave carrier optical modulation communication and signal processing systems.

Analog Optical Modulation

- Applications
  - Analog fiber communications systems or radio on fiber (RoF)
- Requirements
  - High frequency transmission
  - Low loss
  - Low dispersion
  - High performance modulation systems
  - High linearity: the modulated output optical signal is strictly proportional to the input voltage signal
- Defense Market
  - Communications, intelligence, survey (ISR) & Electronic warfare
- Civil Market
  - Mobile communications, airport radar, inter & intra satellites communications

Analog modulation & signal distortion

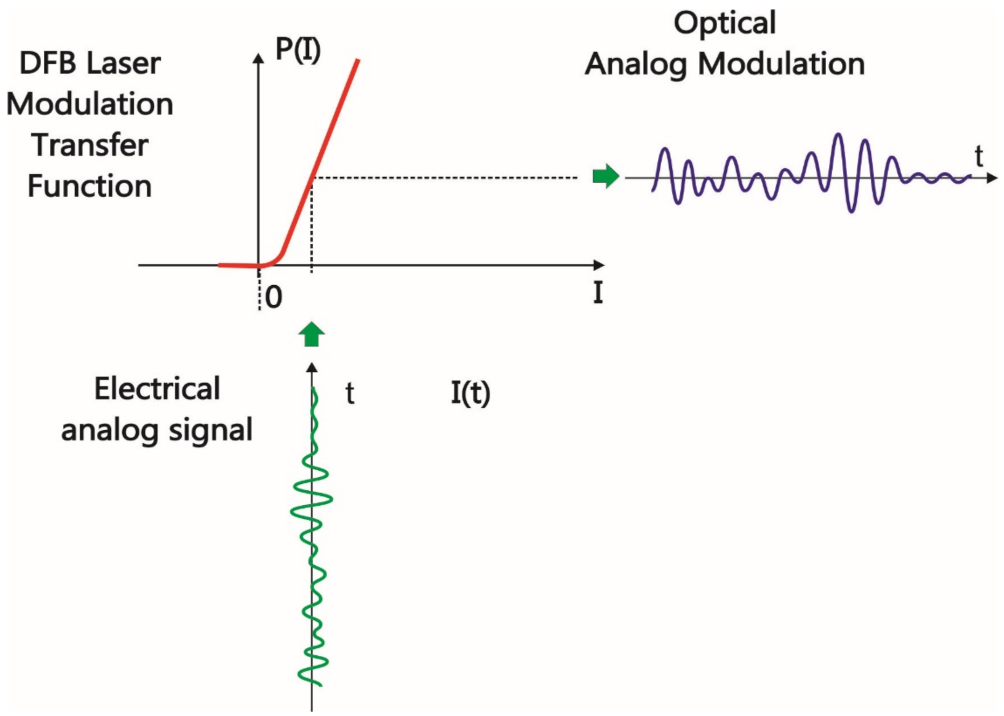
- **Analog modulation system**: faithful restitution of the incoming electrical signal = distortion-free Modulation.

- **Problem**: the Modulation Transfer Function (MTF) cannot be fully linear on the total range.
- Depending on the modulation principle, non linearity can be passive or dynamic.
- Particular attention is paid on 2^{nd} and 3^{rd} order distortion, Composite triple beat (CTB) for instance.

- **Key parameters of an analog communication system:**
  - Gain of the link
  - SFDR (Spurious free dynamic range)
  - Compression point
  - Interception point

Direct modulation of a laser diode versus external modulation

- Direct modulation of the injection current of a laser diode should yield linear modulation considering the optical power characteristic versus driving current.
- Direct modulation is simple and cost-effective.
- However linearity is only available in quasi static regime.



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Demonstration: dynamic modulation of a laser diode and resulting non linearities

Time dependent coupled rate equations of a DFB laser diode

- The MTF is linear only at low frequency
- Linearity assessment must take into account the dynamic behavior of a laser diode

$$\frac{dn(t)}{dt} = \frac{I}{eV} - g_o\left[n(t) - N_o\right]\left[1 - \varepsilon P(t)\right]P(t) - \frac{n(t)}{\tau_n}$$

$$\frac{dP(t)}{dt} = \Gamma g_o\left[n(t) - N_o\right]\left[1 - \varepsilon P(t)\right]P(t) - \frac{P(t)}{\tau_p} + \Gamma\beta\frac{n(t)}{\tau_n}$$

$$\nu(t) - \nu_m = \frac{\alpha_H}{4\pi}\left(\frac{1}{P(t)}\frac{dP(t)}{dt} + \frac{\varepsilon}{\tau_p}P(t)\right)$$

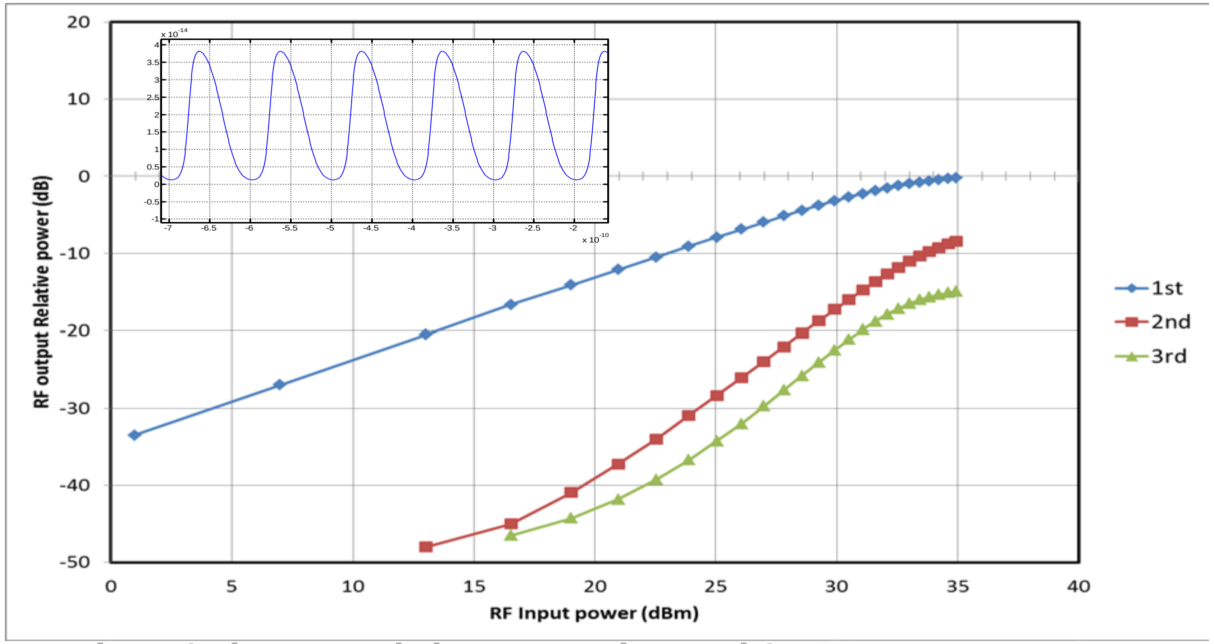
- *n(t): number of carriers in the cavity*
- *P(t): number of photons*
- *ν(t): optical frequency*
- *I: current (A)*
- *V: volume of the cavity*
- *e: electrical charge of the electron*
- *α_H: Henry coefficient*
- *Γ: Confinement coefficient*
- *go: optical gain*
- *No: carrier density at transparency*
- *ε: gain compression coefficient*
- *τn: carrier life time*
- *τp: photon life time*
- *β: Spontaneous emission coupling*

Simulation & comparison between External Modulation and Direct modulation

DFB laser dynamic response

- High distortion of the output modulated optical power.
- 2^{nd} & 3^{rd} order distortion.

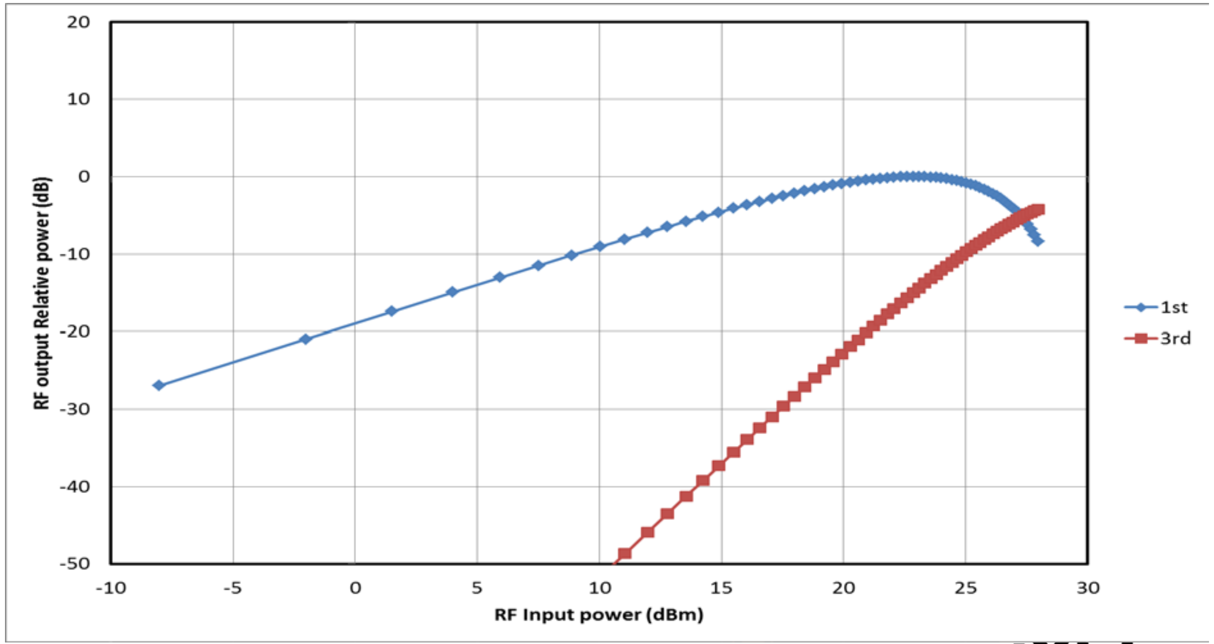
Direct modulation of a DFB laser : Example at 10GHz



Mach-Zehnder dynamic response

- The MTF is the sine of the applied voltage.
- When biased at $-\frac{\pi}{2}$, only 3rd harmonic distortion occurs.

$$P(t) = \frac{P_o}{2}\left[1 + \sin\frac{\pi}{V_\pi}V(t)\right]$$



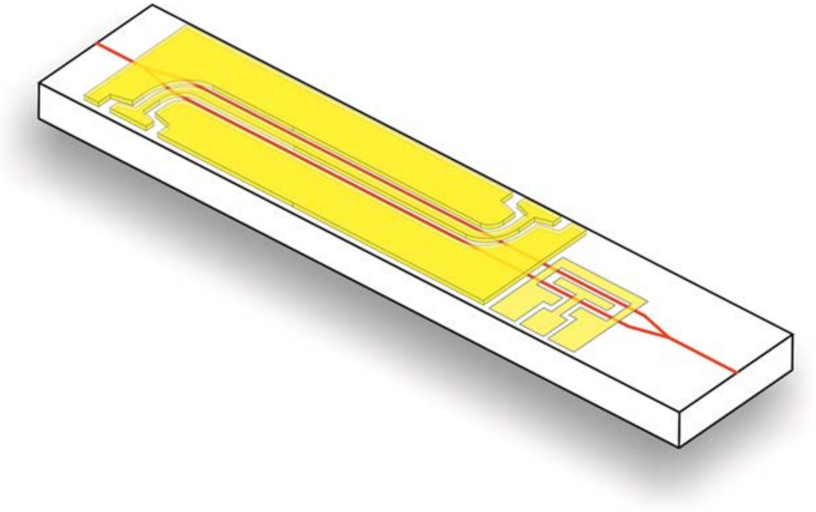
Lithium niobate optical modulator

Description

- An optical waveguide circuit integrated in a lithium niobate substrate.
- comprises an input and an output Y splitter connected by two parallel straight waveguides optical arms of the Mach-Zehnder interferometer.
- CPW phase matched & traveling microwave electrodes.
- Separated DC electrodes.
- Input and output single mode polarisation maintaining (PM) optical fibers.

- **Optical Modulator** = electrical-to-optical converter

- **Photodetector** = optical-to-electrical converter



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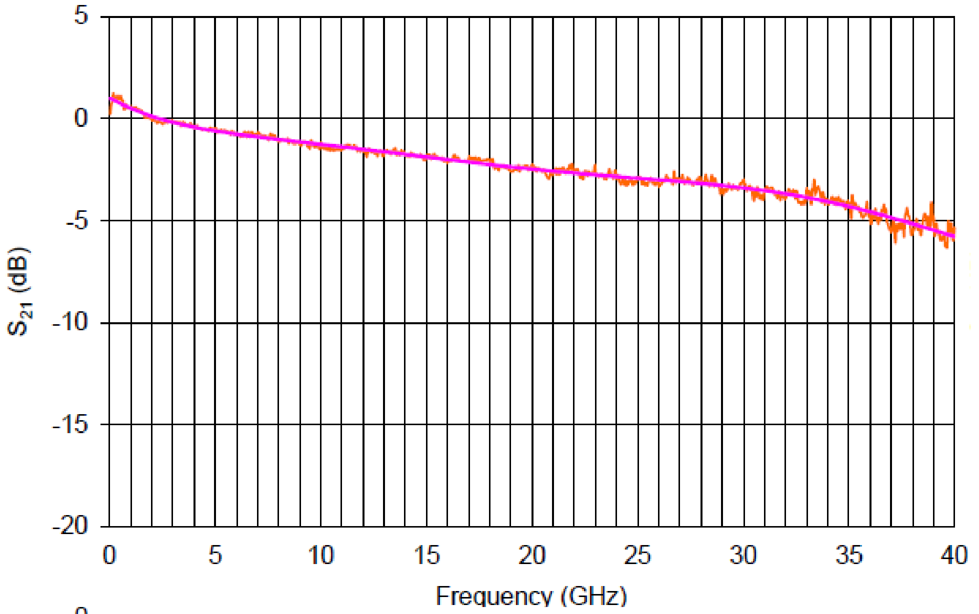
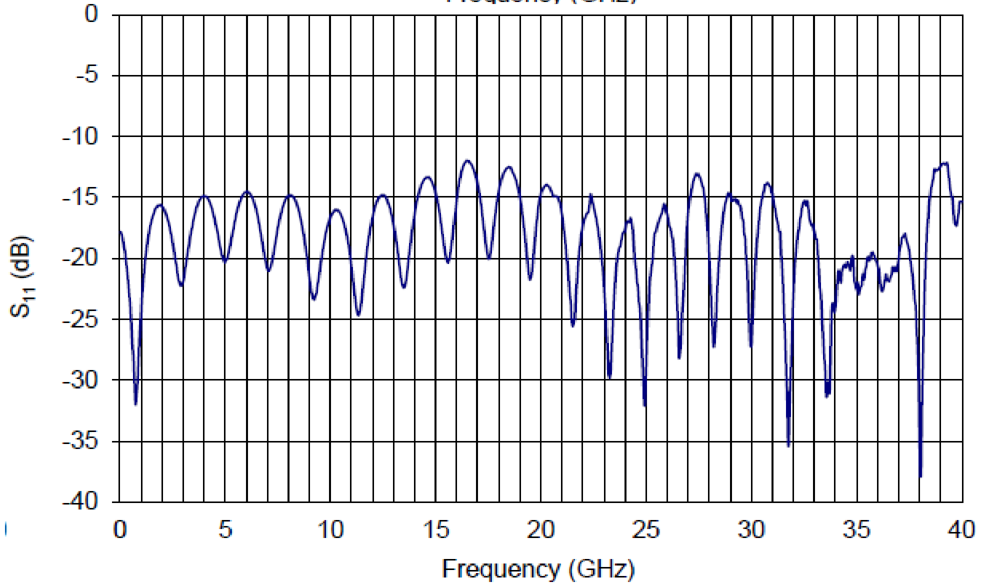
Analog modulator MXAN-LN in the C & L bands

Parameters	Unit	Typical
Half wave voltage DC port VπDC	V	6
Half wave voltage DC RF port VπRF	V	3 ; 5
Insertion loss IL	dB	2,5 ; 4
Static extinction ratio SER (dB) (> 25 dB)	dB	> 25
Optical return loss ORL	dB	> 45
Polarisation extinction ratio PER	dB	> 28
Electro-optic bandwidth : E-O S_{21} @-3dB	GHz	> 15 ; > 32
Electrical return loss ERL S_{11} (> 12 dB)	dB	> 12
Harmonics supression	dB	> 60
SFF packaging small footprints	mm	< 85





Factor of Merit

- The factor of Merit (FoM) is an interesting characteristic of the analog modulator to be considered.
- Trade-off parameter taking into account the effective halfwave voltage $V\pi eff$ at the operating carrier frequency and the insertion loss α of the device.
- Defines the efficiency of electrical /optical /electrical power conversion in the side band of modulation at the modulator output for a given input laser power.

$$FoM = (10^{-\alpha/10} / V\pi eff)^2$$

- Exemple taken with the MXAN-LN-40:

  $V\pi$ = 5 V @ DC & $V\pi eff$=7 V @ 35 GHz

  BW = 35 GHz @ -3 dB

  ⇨ FoM (35 GHz) = 1.1×10^{-2} with α = 2.6 dB

Knowing the modulator characteristics, evaluate your analog fiber link performances

Données: Remplir les paramètres modulateur, laser, détecteur

Pertes modulateur(dB)	Sensibilité Photodiode (A/W)	Puissance laser (W)	Vpi @ DC	Bande passante modulateur @-3dB	Fréquence de travail (GHz)
3,00	0,80	0,01	4,50	20,00	18,00

Résultats : Performances de la liaison analogique

Vpi effectif (volt)	Gain de la liaison (dB)	Amplitude IIP3 (V)	Puissance (dBm) IIP3	Compression P1dB (dBm)	Puissance sortie (dBm) OIP3	Noise Figure (dB)	SFDR (dB/Hz$^{2/3}$)
6,14	-25,80	5,53	24,84	15,45	-0,96	38,80	106,69

Références fixes

Amplitude (Volt) pour 0dBm	Bande passante (Hz)	OSNL (dBm/Hz)	BNL (dBm/Hz)	Résistance Charge (ohm)
0,22	1,00	-161,00	-174,00	50,00

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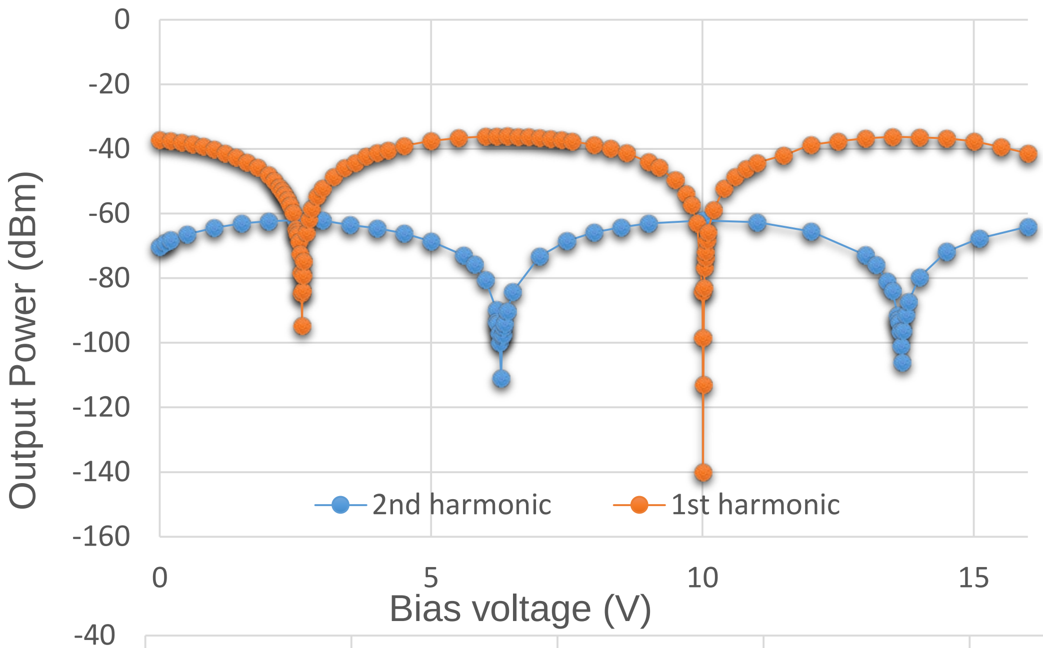
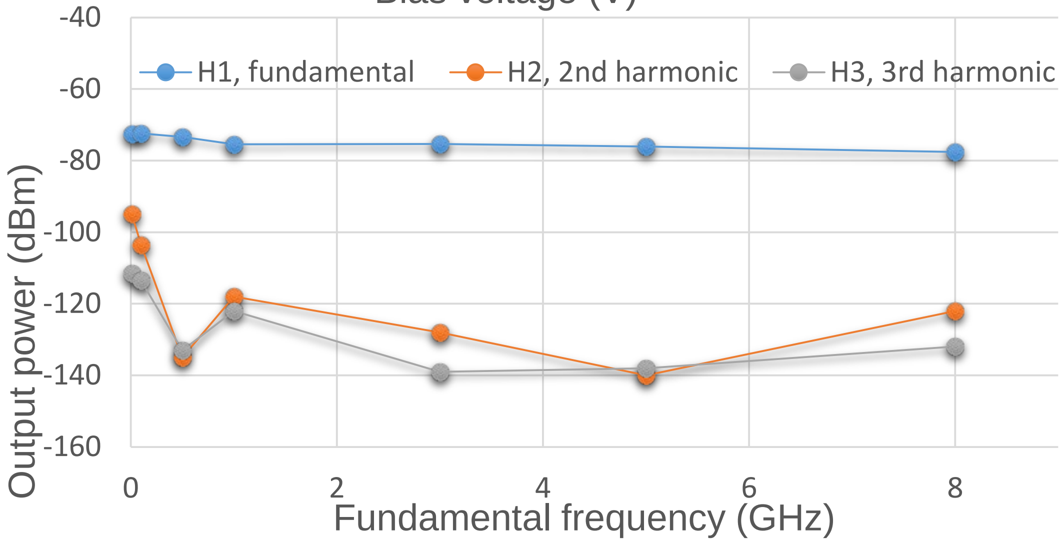
Characterization

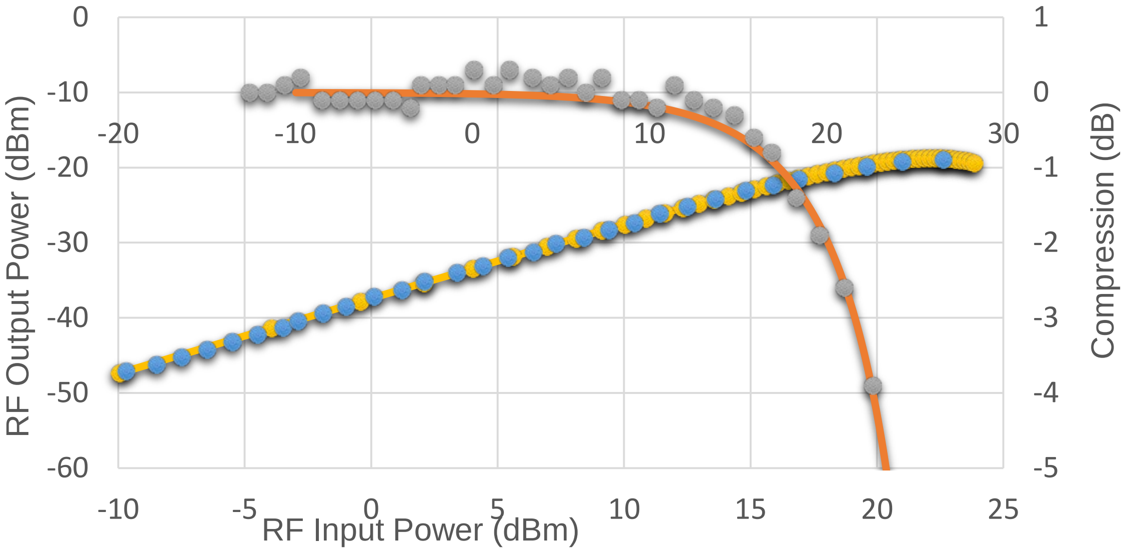
MFT of 1st and 2nd Harmonics



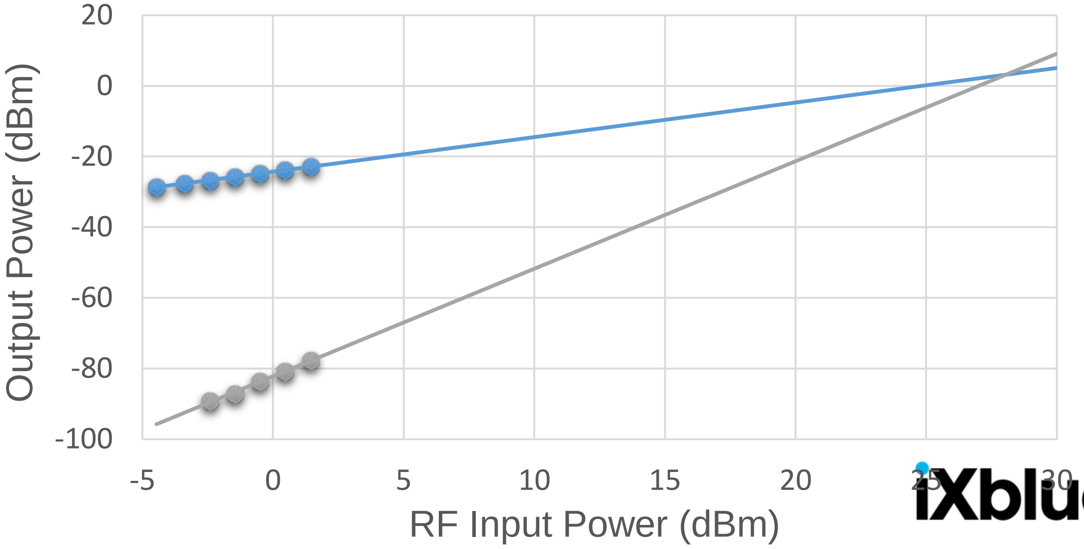
2nd & 3rd Harmonics rejections



Compression & Linearity



Compression & Linearity at 1.5 GHz , 1550nm wavelength and 12dBm input optical power; VπRF=6V BW=18 GHz IL=4.0dB



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A family of iXblue analog optical amplitude & Phase Modulators

Item	Description
MXAN-LN-10	C+L Bands 10 GHz Analog Intensity Modulator
MXAN-LN-20	C+L Bands 20 GHz Analog Intensity Modulator
MXDO-LN-20	C+L Bands 20 GHz Analog Dual Output Intensity Modulator
MXAN-LN-40	C+L Bands 40 GHz Analog Intensity Modulator
MXIQER-LN-40	C+L Bands 20 GHz IQ & CS-SSB Modulators
MPZ-LN-20	C+L Bands 20 GHz Phase Modulator
MPZ-LN-40	C+L Bands 40 GHz Phase Modulator

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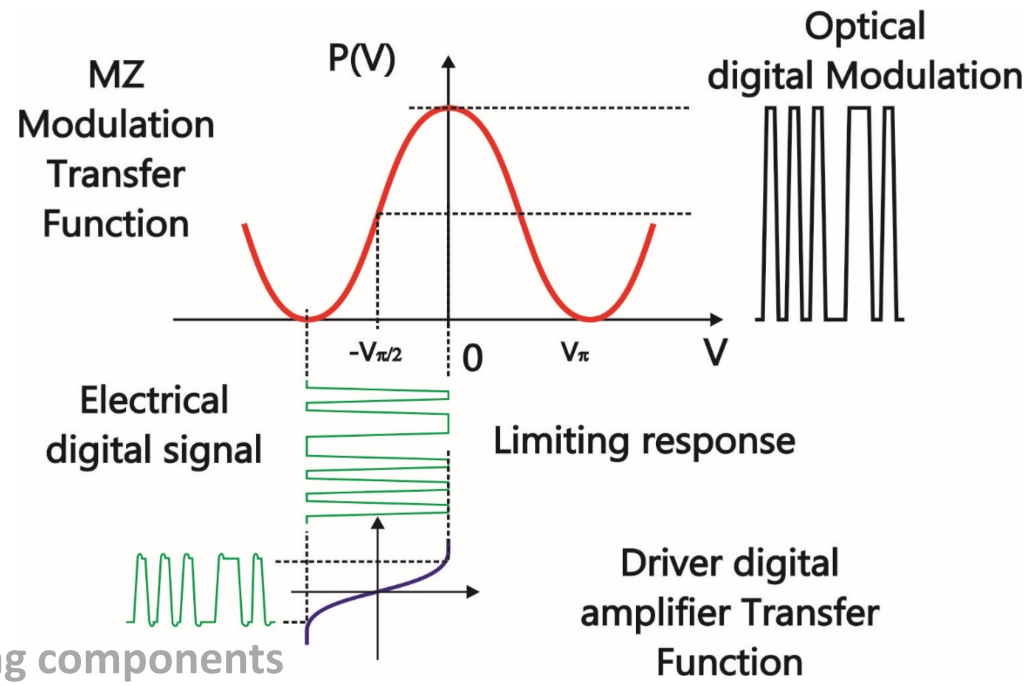
Digital driver amplifier vs Analog driver amplifier: differences and similarities

- A microwave modulator driver amplifier is required to adjust the level of the incoming signal (typ. 500 mVpp) to the half-wave voltage of the optical modulator (Typ 5 Vpp),
- Typical gain 20 dB
- For On-Off Keying (OOK) communication, the digital driver amplifier needs to show only a limited response where the saturation swing voltage fits exactly the $V\pi$ of the optical modulator



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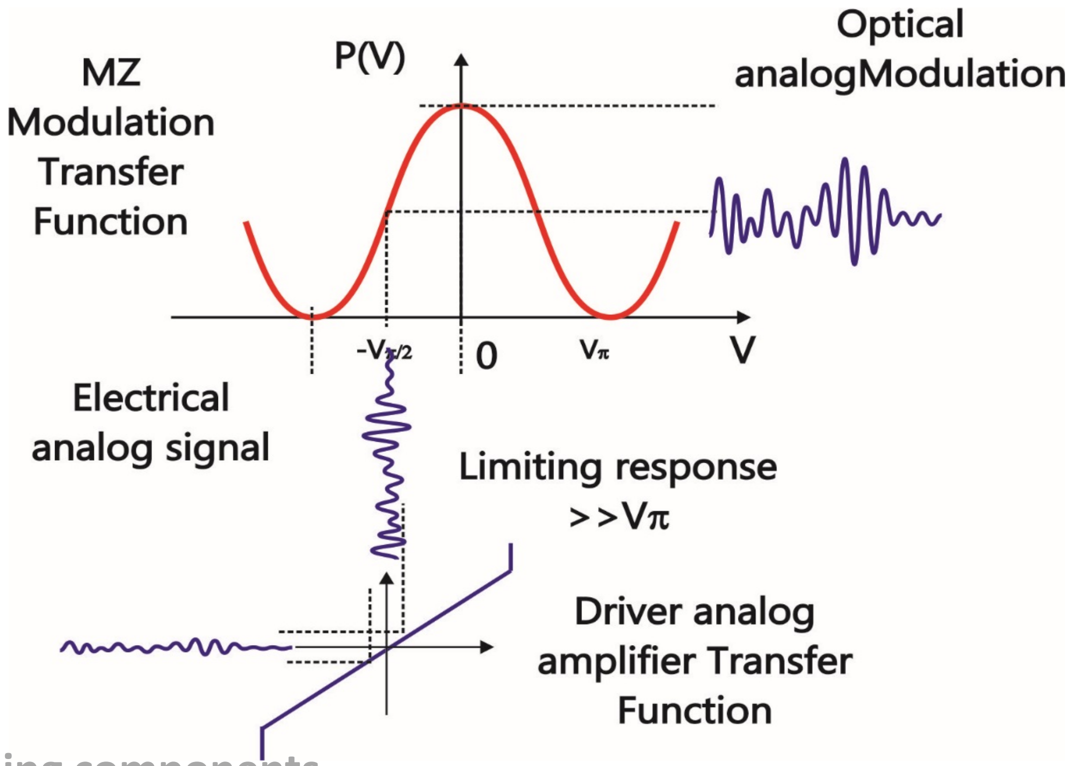
Analog modulator driver amplifier

- The analog modulator driver is a GaAs MMIC distributed amplifier showing saturation of the peak-to-peak swing voltage >> $V\pi$ of the optical modulator.
- The driver amplifier itself must show a high linearity on the full dynamic range of the output voltage.
- With this condition, the sine shape of the MTF of the modulator is the only source of 3rd harmonic distortion.



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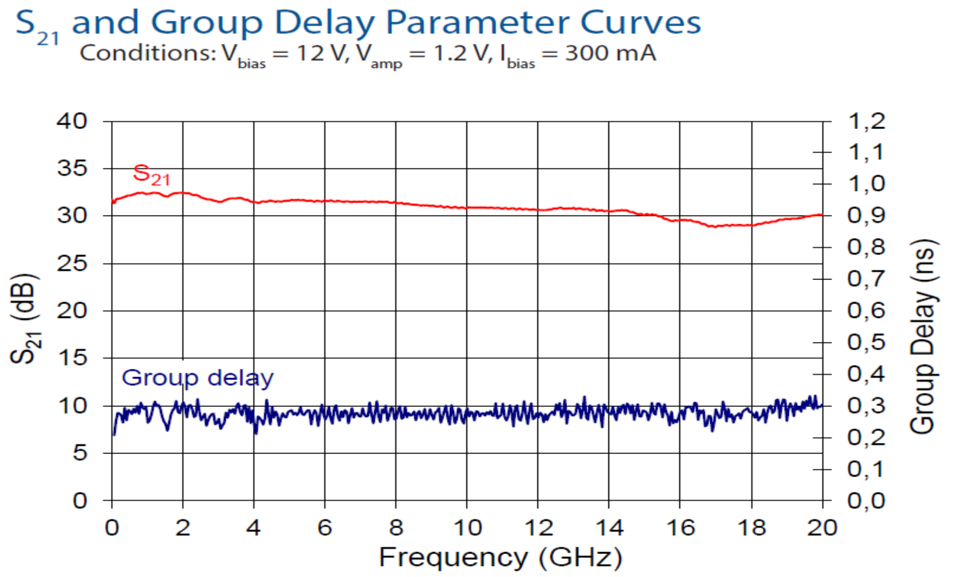
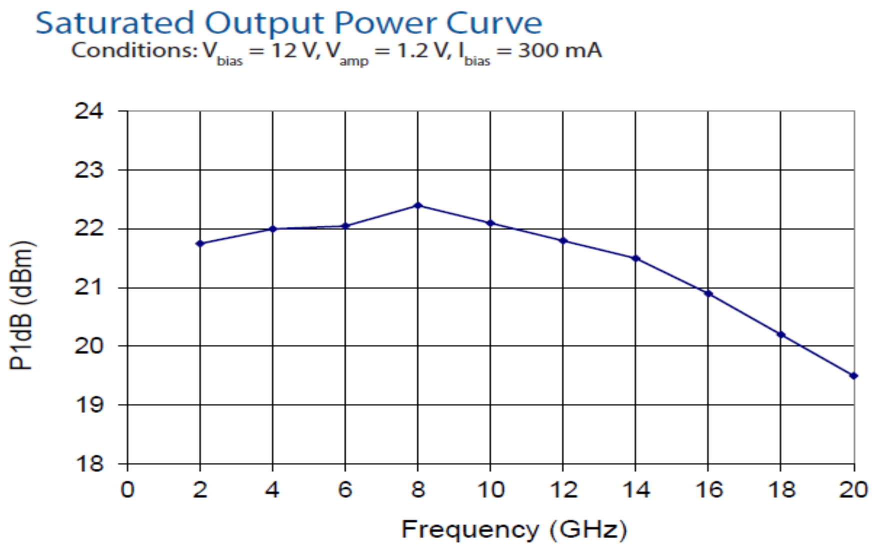
Analog modulator driver amplifier

iXBlue Photonics produces analog drivers. The **Photline DR-AN** serie shows the following performances

- Bandwidth > 20 – 30 GHz
- Output swing voltage 9 – 12 V
- Gain 18 – 30 dB





A family of iXblue analog modulator driver amplifier

Item	Description
DR-AN-10-MO	10 GHz Analog Medium Output Voltage Driver Module
DR-AN-10-HO	10 GHz Analog High Output Voltage Driver Module
DR-AN-20-MO	20 GHz Analog Medium Output Voltage Driver Module
DR-AN-20-HO	20 GHz Analog High Output Voltage Driver Module
DR-AN-40-MO	40 GHz Analog Medium Output Voltage Driver Module
DR-AN-28-MO	28 GHz Analog Medium Output Voltage Driver Module

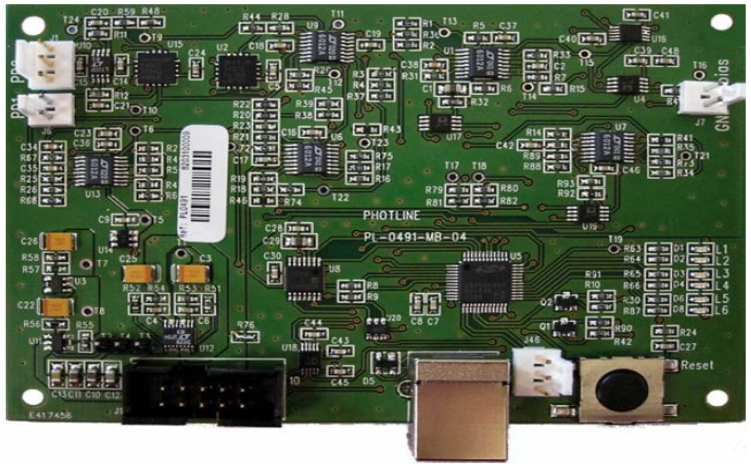
Analog Modulator Bias controller

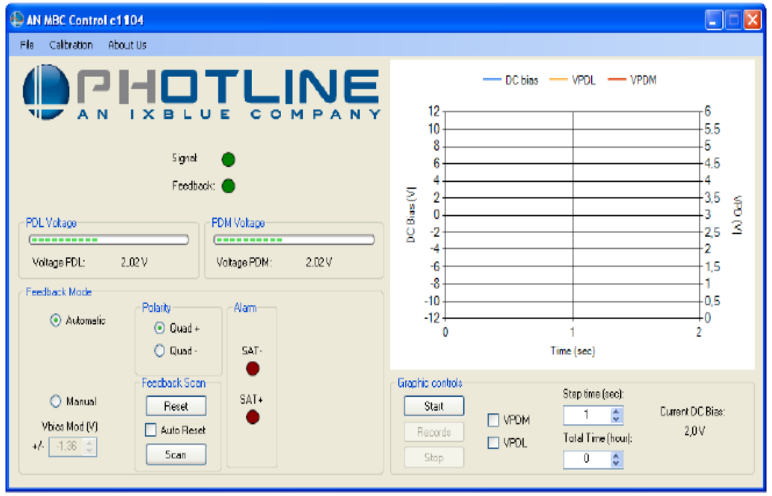
iXBlue photonics develops and produces

- Modulator bias controller for analog application

- The dither free feedback loops of the **Photline MBC-AN** allows to maintain the static phase shift of the modulator at and fixed value.

- A graphical user interface allows to monitor the bias controller parameter and transmission of the modulator.

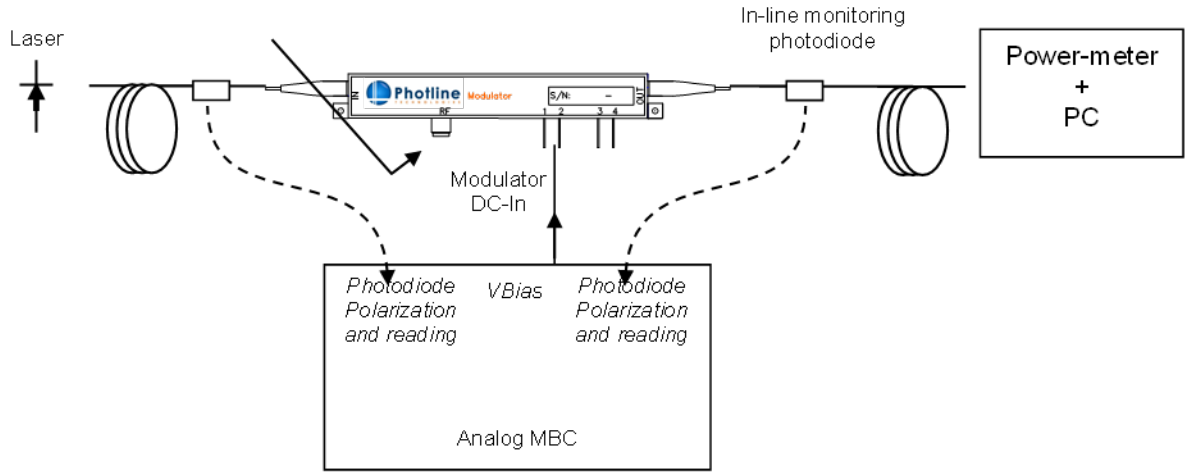


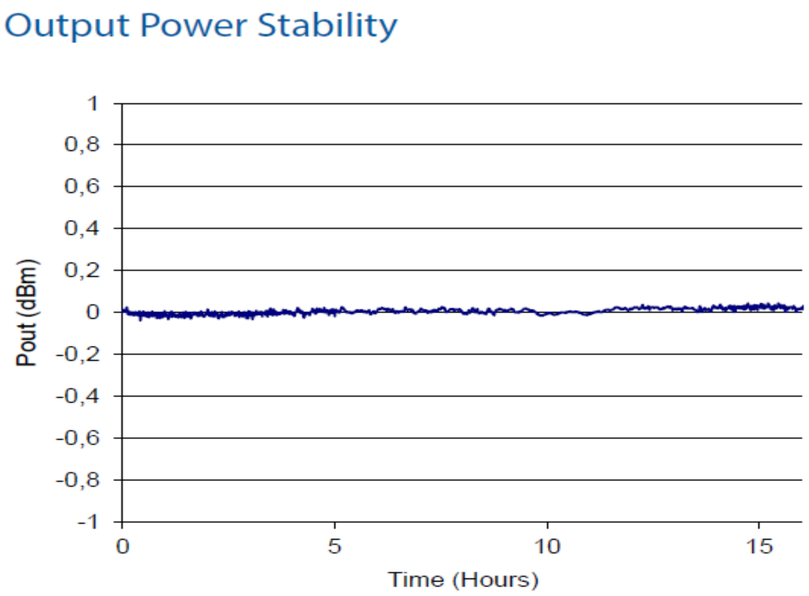


Analog Modulator Bias controller

Set up

- The Laser source optical power and modulator output optical power are measured and compared.
- An electronic feedback loop delivers a bias voltage to compensate any phase drift of the MZM.
- It maintains the working point on the modulator transfer function at a fixed position (-$\pi/2$ phase shift) minimizing 2nd harmonic distortions.
- An acquisition of the data with a PC can be launched during operation to monitor the output optical power as well as the bias voltage.





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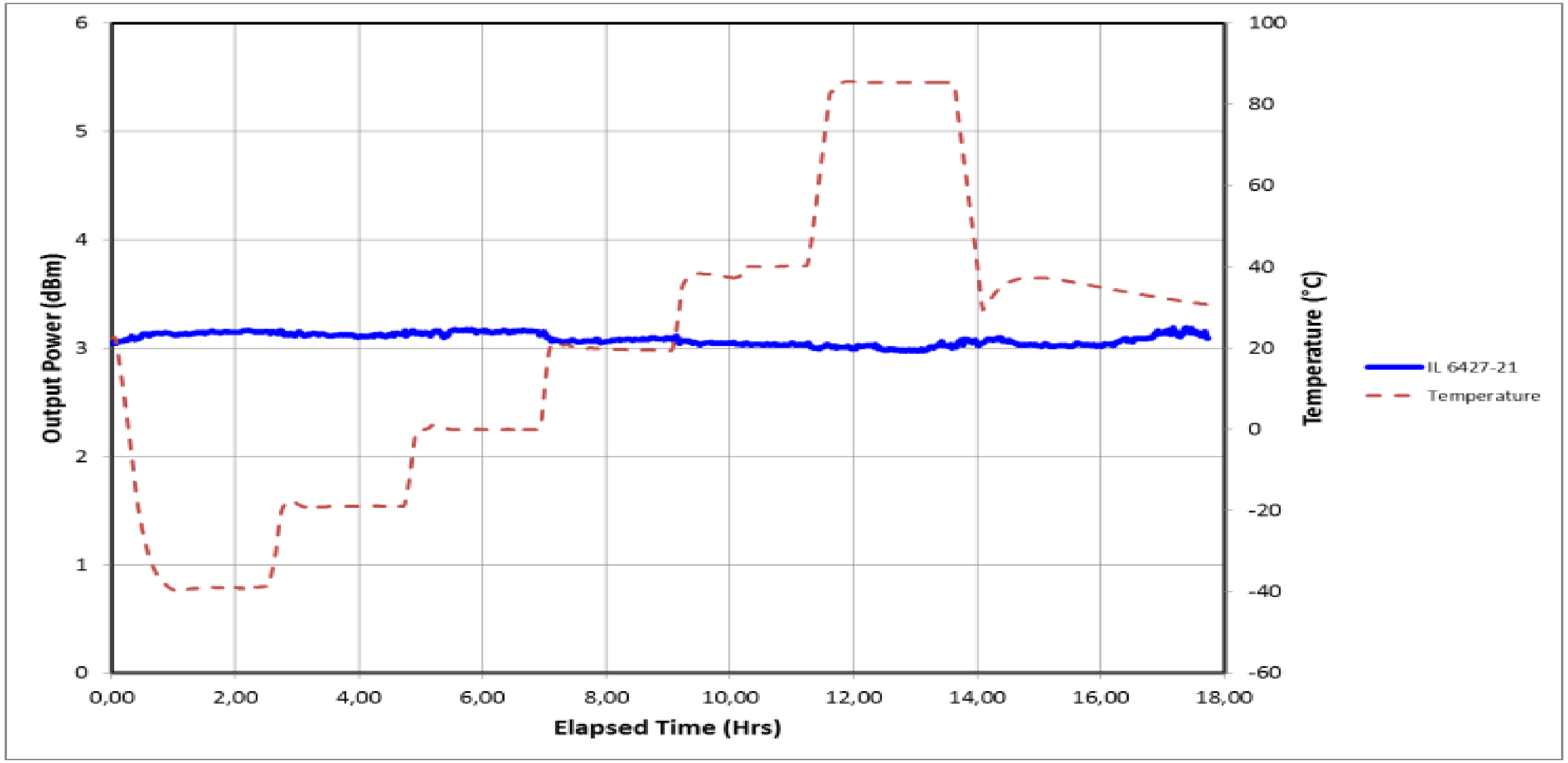
Characterization

- Operating condition: the MXAN & MBC-AN were temperature tested in working condition.
- A follow-up by temperature step was done. The duration of each temperature step is 2 hours for each.
- Temperature steps: -40 °C, -30 °C, 0 °C, +20 °C, +40 °C, +85 °C



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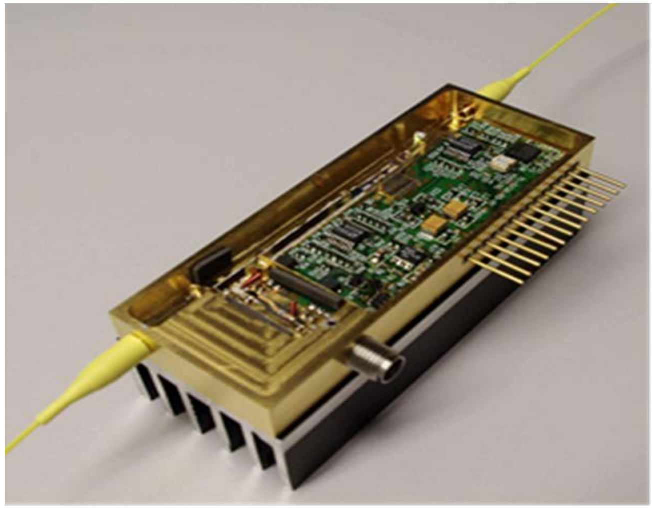
Analog Modulator Bias controller

Item	Description
MBC-AN-board	Bench-top or Board Modulator Bias Controller for analog applications
Quadrature operating point Dither-free Operation USB remote control Extended wavelength range	OPT-PD/TAP tap coupler with photodiode available for 800 nm, 1000 nm, 1310 nm, 1550 nm, 2 µm



Co-integration in a single package housing of the analog modulator, the linear RF diver and the dither-free bias controller

Exemple of Applications CS-DSB & CS-SSB

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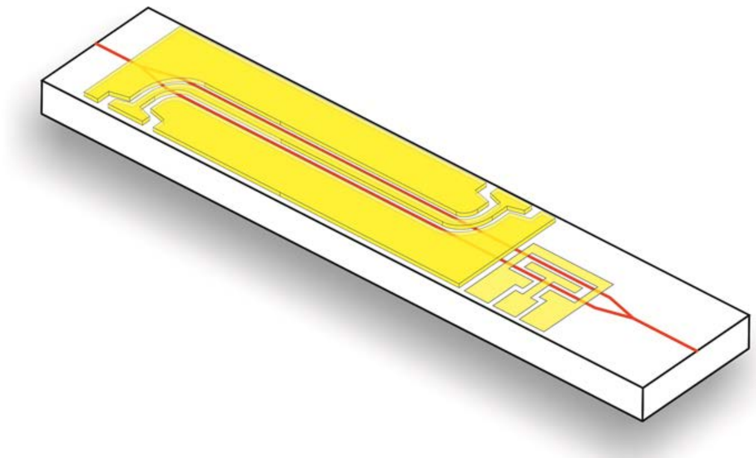
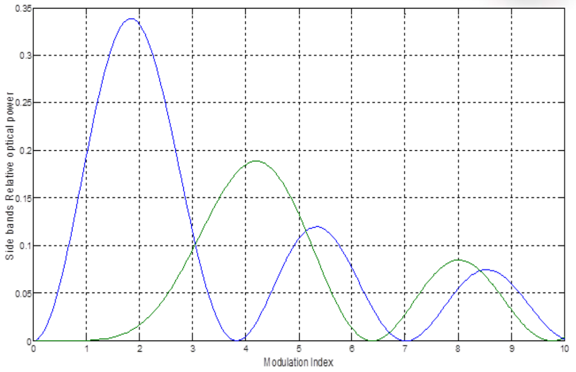
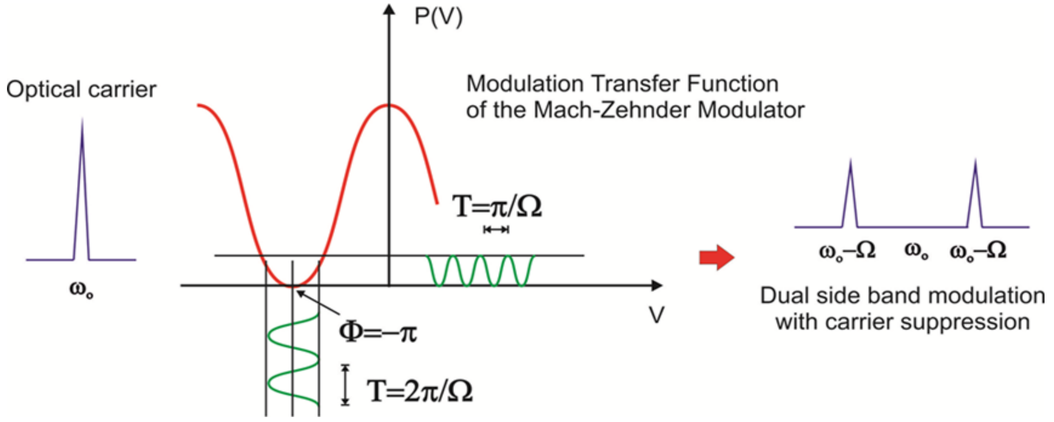
Carrier Suppression and Dual Side Band modulation (CS-DSB) - I/II

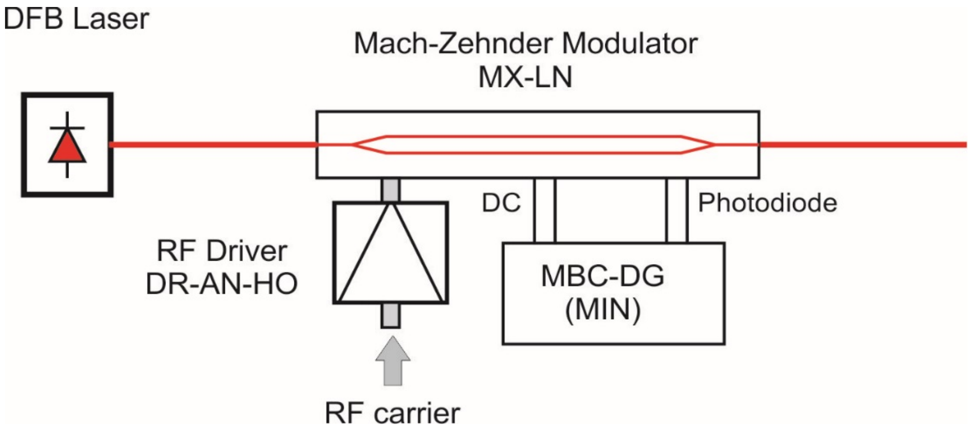
Sinusoidal Modulation of the MZM biased at MIN i.e. $-\pi$ rad

➡ Carrier suppression and dual side band generation







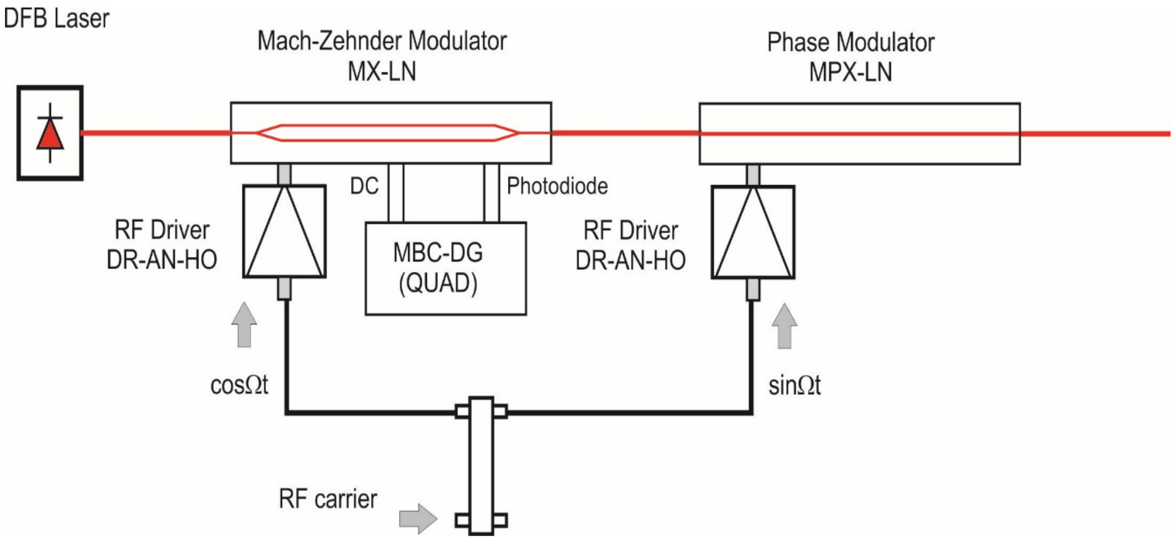


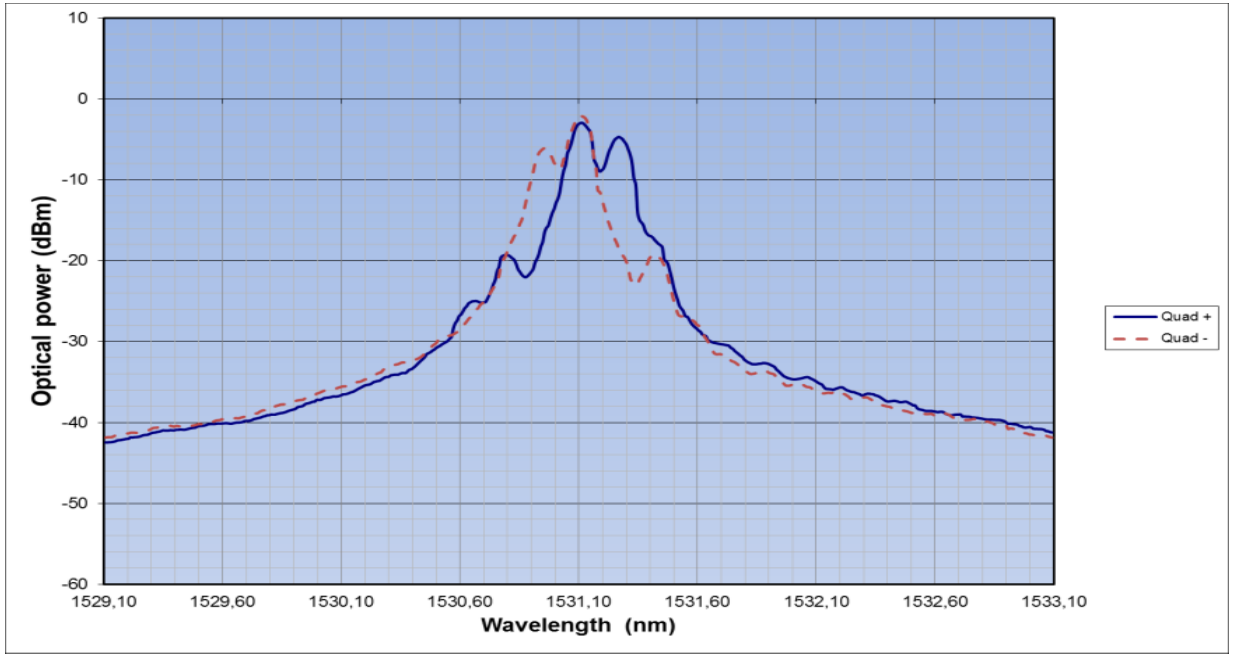
Carrier Suppression and Dual Side Band modulation (CS-DSB) - II/II

Configuration obtained by cascading one MZM with one phase modulator.

A cosine signal is applied to the MZM while a sine signal is applied to the phase modulator PM.

The MZ modulator is biased at $-\pi/2$, ie (quadrature).





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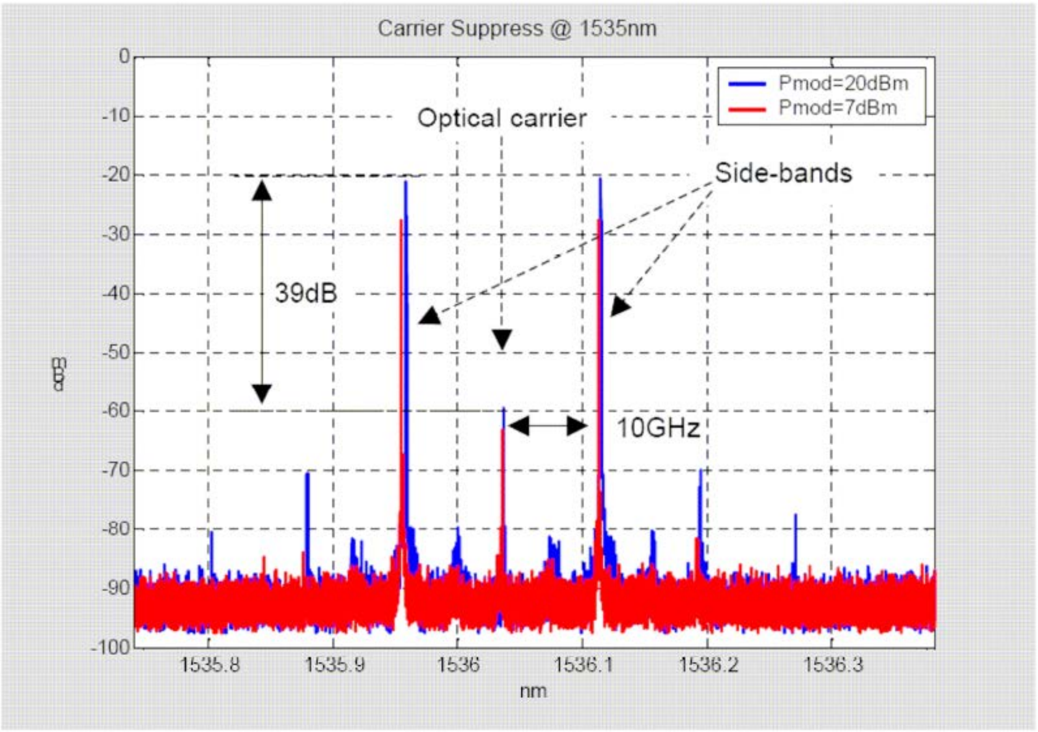
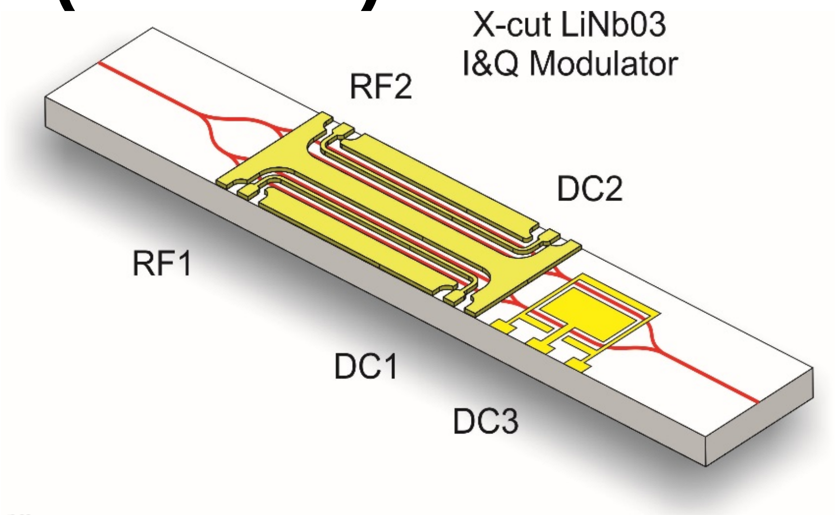
Complex analog modulation instruments: ModBox-CS-DSB

- Fully optimize, turn-key modulation unit.
- High contrast and suppression on the carrier at 40 dB.
- High supression stability.

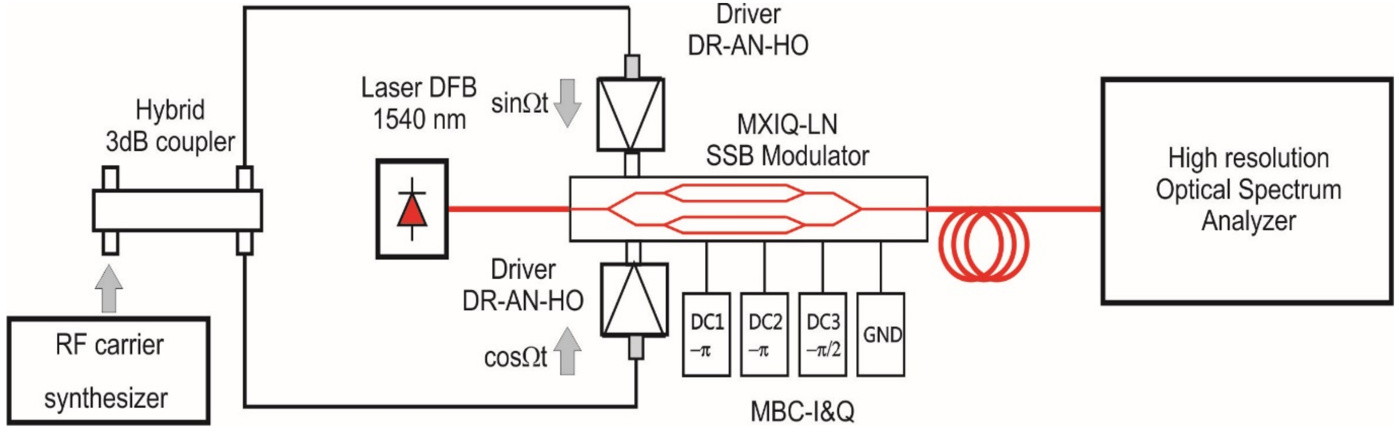
Turn-Key ModBox-Cband-DSB

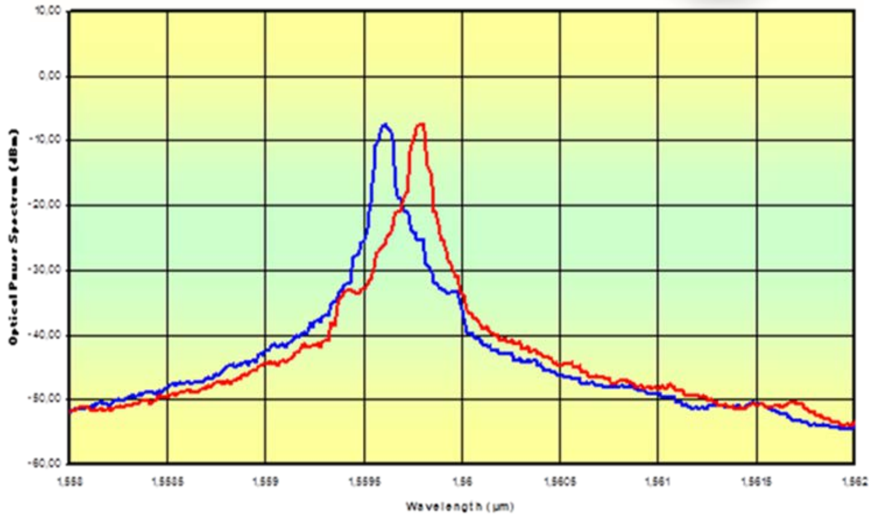


Carrier Suppression and Single Side Band (CS-SSB)



- I&Q / CS-SSB Modulator = 2 nested Mach-Zehnder embedded in a main Mach-Zehnder.
- Each RF port is modulated with an RF carrier applied in quadrature
- Each nested Mach-Zehnder is biased at MIN (-π radian)
- Main Mach-Zehnder can be phase shifted from –π/2 to +π/2





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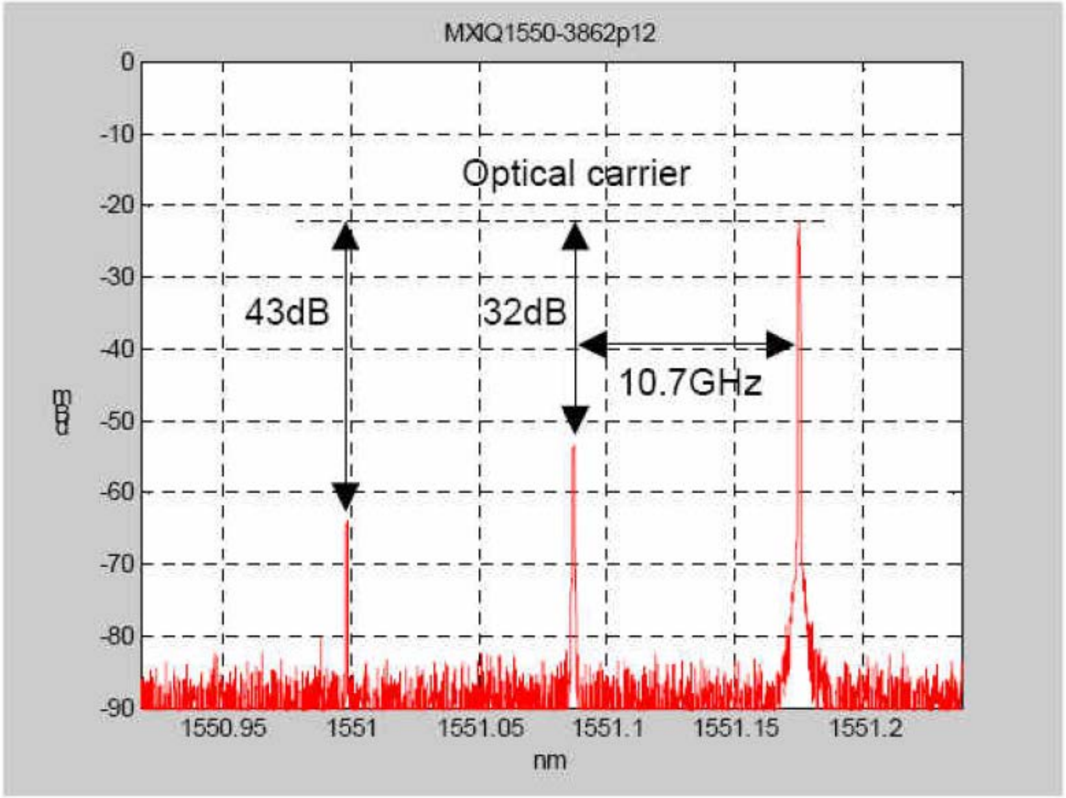
Complex analog modulation instruments: ModBox-CS-SSB

- Fully optimize, turn-key modulation unit.
- High contrast and suppression on the carrier and one side band at 30 dB.
- High supression stability.

Turn-Key ModBox-Cband-DSB



Exemple of Applications VNA & Analog ModBox

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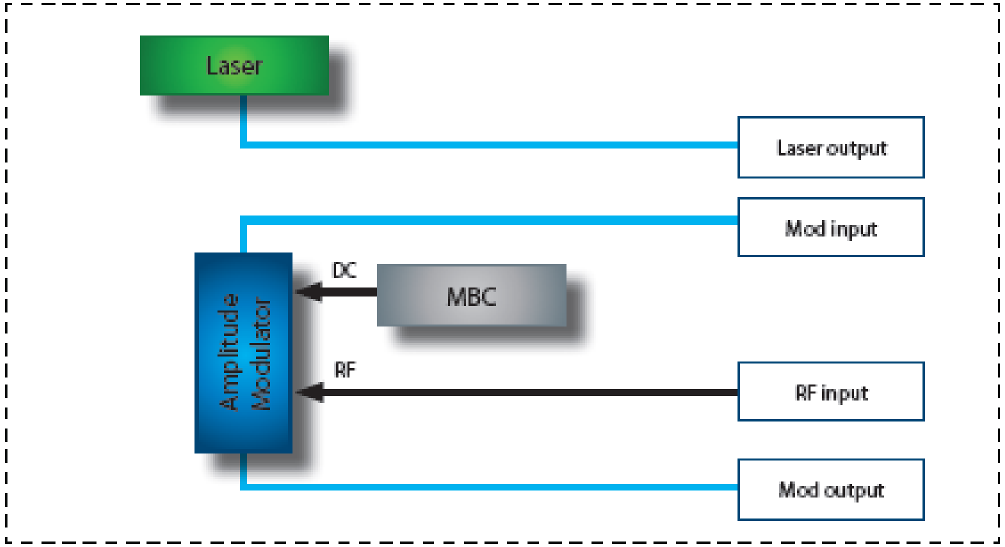
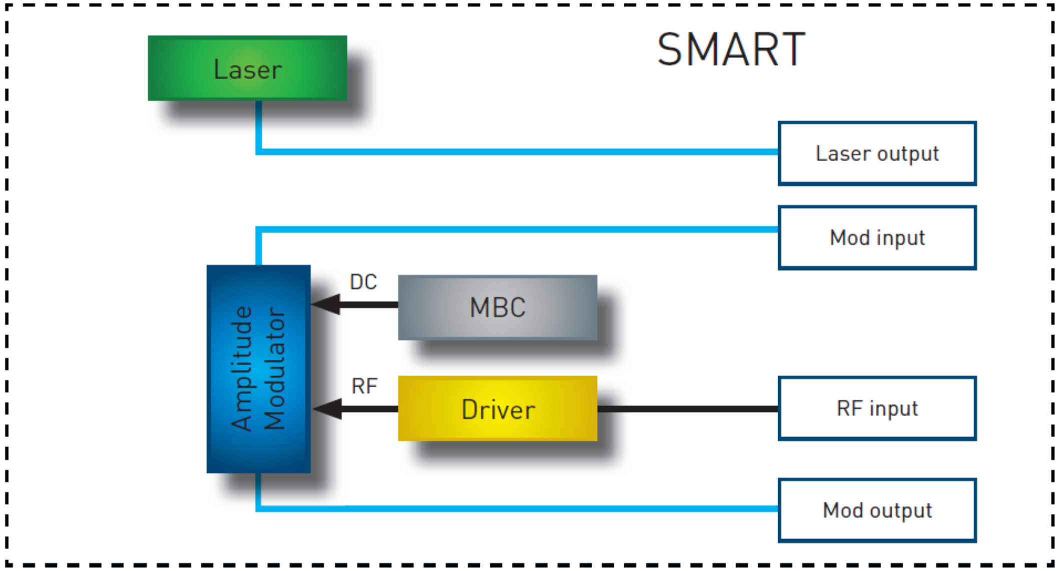
Complex analog modulation instruments: ModBox-VNA

- The **Photline ModBox-VNA** is a broadband optical transmitter designed to be associated to vectorial network analyzers (VNA) working in the optical domain.
- The ModBox-VNA integrates a low-noise DBR laser and an optical lithium niobate modulator showing broad modulation bandwidth. The modulator is biased at quadrature for optimized linearity thanks to an automatic analog and dither-free bias controller.
- Available at 850 nm, 1310 nm and 1550 nm, up to 40 GHz, 65 GHz.



Complex analog modulation instruments: ModBox-AN

- The Photline ModBox-AN is an optical transmitter dedicated to analog transmission.
- The Photline ModBox-AN features an optional internal laser source. The unit is optimized to generate a high performance and high stability optical analog signal from its internal laser source and a user supplied RF modulation signal.
- Available at 850 nm, 1310 nm and 1550 nm, up to 40 GHz, 65 GHz.



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Conclusions

- Lithium niobate technology is a mature and reliable technology for optical modulator (phase and amplitude) manufacturing.
- Thanks to qualifications steps achieved, the iXblue modulators (**Photline MX-AN**) find applications in space and defense.
- Controlled fabrication process at an industrial level.
- Flexibility with architectures and design.
- Many solutions to answer analog complex modulation problems: DSB, SSB, CS-SSB.
- Available technology at any wavelength from near infra red (780 nm) to telecom wavelengths (1310 nm and 1550 nm) up to mid infra red (2000 nm).
- MMIC GaAs distributed driver amplifier (**Photline DR-AN**) are designed to reach an optimal coupling and interaction between incoming signal and optical modulation.
- Bias controller with dither free principle (**Photline MBC-AN**) allows modulation at quad ($-\pi/2$) to reach the best linearity and minimized 2^{nd} order harmonic distortion.
- Complex assembly and integration yields friendly use instruments (**Photline ModBox-VNA & ModBox-AN**).

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