Introduction to Exail Modulator Bias Controller (MBC)

exail

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Introduction

This technical note aims to give intensity modulators users the basics to select and apply the proper RF and bias voltages to their device.

Waveguide type $LiNbO_3$ Mach-Zehnder optical modulators offer multiple benefits for the modulation of light:

- High modulation speed capabilities (several x10 GHz).
- Compactness.
- Reliability.
- Environmental robustness.

They have been widely used in the telecom industry for nearly two decades (several x 100 000 $LiNbO_3$ intensity modulators are operating in the fiber optics networks all over the world), and they are also used in an increasing number of photonics applications such as:

- fiber optics sensors.
- fiber lasers systems.
- measurement equipment.
- RF over fiber….

Principle – Transfer function

Waveguide $LiNbO_3$ Intensity modulators are Mach-Zehnder type interferometers: an input waveguide is split into two paths that are then recombined into an output waveguide (see figure1). The two paths make up the two arms of the interferometer and the optical index modulation induced on each of them creates the intensity modulation at the output of the device.

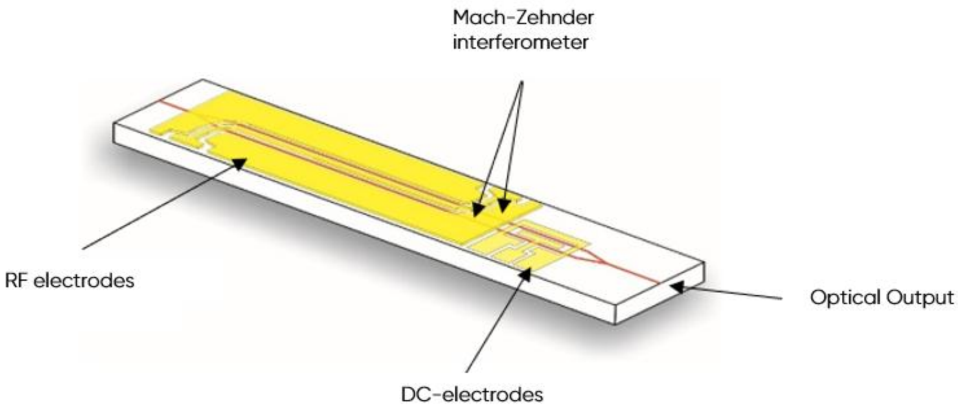

Figure 1: Schematic view of a $LiNbO_3$ intensity modulator chip

The optical index modulation is induced by an electric field into the electro-optic material, and the electrical field is obtained by applying a voltage between electrodes – that's the electro-optic effect. There are generally two pairs of electrodes: modulation electrodes (often called RF electrodes) and DC electrodes (also called bias electrodes).

The Modulator Transfer Function – MTF – (see figure 2) of an intensity modulator driven by a time dependent voltage V(t) is given by:

$$I_{out}(t) = T_{mod}.\frac{I_{in}}{2}\left[1 + cos\left(\frac{\pi}{V_\pi}V(t) - \phi\right)\right]$$

with:

- I_{out} : output intensity.
- I_{in} : input intensity.
- ϕ : phase term.
- T_{mod} : optical transmission of the device.
- V_π : half-wave voltage of the modulator.

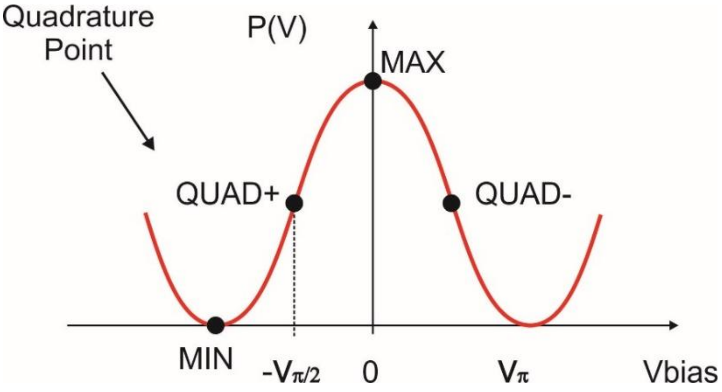

Figure 2: MTF of a LiNbO3 *intensity Mach-Zehnder modulator*

Theory and reality

The intensity modulators are designed to have equal arms and thus balanced optical paths. In theory, the phase term ϕ should be zero. However, there is always a small difference between the two optical paths due to material inhomogeneity, manufacturing tolerances…This imbalance explains the ϕ phase term in the MTF.

To operate the intensity modulator and obtain the desired light modulation, one must apply two well suited electrical voltages to the modulator: a modulation voltage V(t) (also called RF voltage) and a DC voltage (also called bias voltage).

Operating point

The modulator operating point is the point on the transfer curve around which the modulation signal is applied. It has to be selected depending on the targeted application. Some examples are given below:

1) *Digital communication, NRZ modulation format -* ***QUAD***

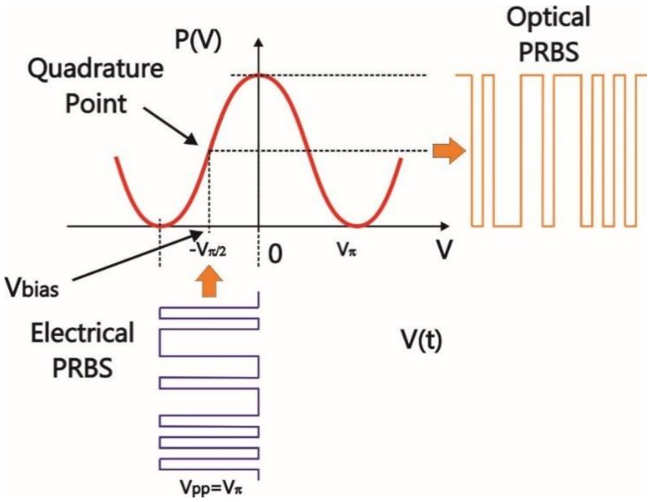

Figure 3: Electrical 10 Gb/s data stream with V_π peak-to-peak voltage applied to an intensity modulator to generate a high SNR 10 Gb/s OOK optical data stream

2) *Digital communication, DPSK modulation format -* ***MIN***

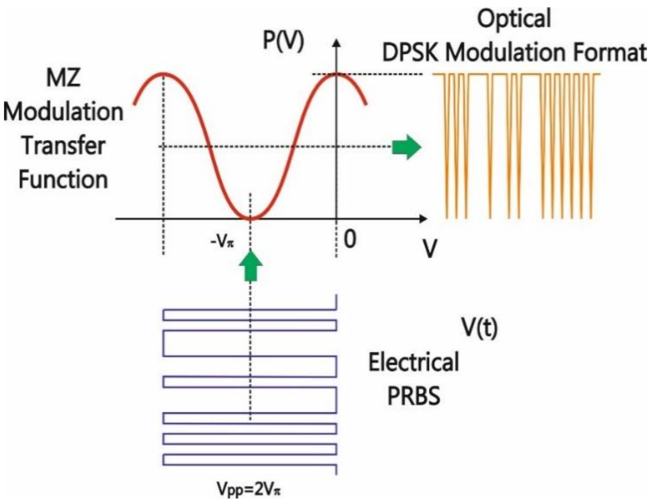

Figure 4: Electrical 20 Gb/s data stream with 2 x V_π peak-to-peak voltage applied to an intensity modulator to generate a high SNR 20 Gb/s DPSK optical data stream

3) *Analog modulation –* ***QUAD***

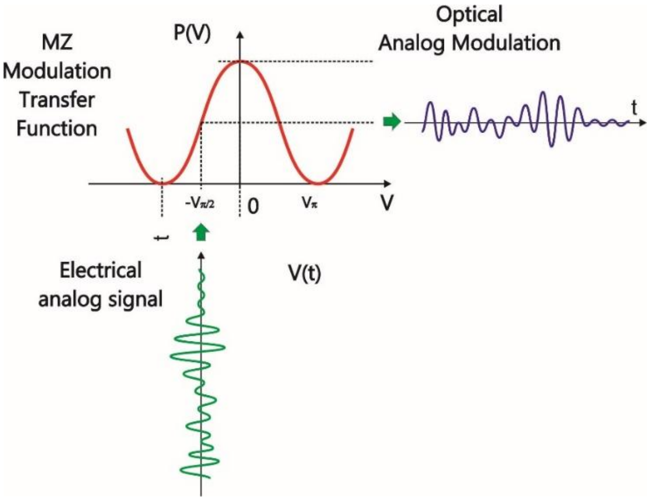

Figure 5: Analog electrical signal with < V_π peak-to-peak voltage applied to an intensity modulator to generate a faithful optical reproduction

4) *Pulse generation –* ***MIN***

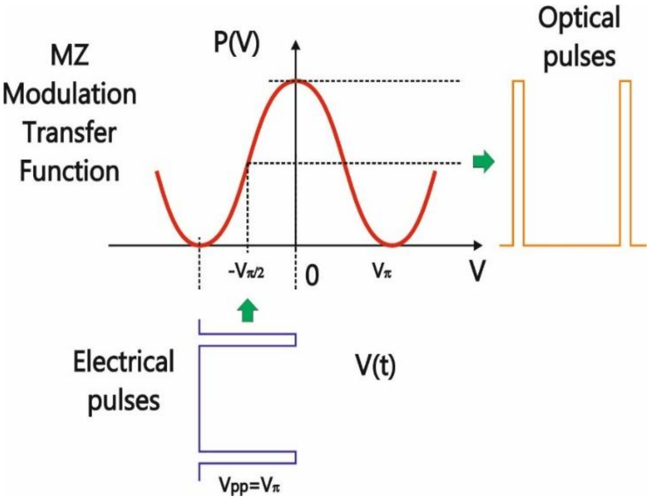

Figure 6: Pulse electrical signal with V_π peak-to-peak voltage applied to an intensity modulator to generate optical pulses with high extinction

Why bias voltage?

As mentioned above, the Mach-Zehnder interferometer is not perfectly balanced. Moreover, it is subject to drift caused by thermal changes, thermal inhomogeneity, aging, photorefractive effects, static electrical charge accumulation…

This drift causes the Modulator Transfer Function to move in the horizontal direction; the modulation signal is then applied to a changing operating point, that can strongly modify the obtained modulation – especially when working at the MIN point. The role of the bias voltage is to counteract this effect.

The bias voltage applied to the DC electrodes aims to:

- Selecting the desired operating point of the modulator.
- Compensating for the possible modulator drift and locking the device operating point so as to keep stable operation conditions.

The bias voltage can be supplied by a simple voltage source and manually adjusted so as the desired operating point is reached. In such conditions, the voltage will have to be readjusted manually in case of a drift of the modulator over time. This may be workable in laboratory with low drift modulators and stable environmental conditions.

However, for a long-term operation and especially in all systems having to operate over changing temperature conditions, an automatic bias control circuit is necessary so as to permanently supply the right DC voltage and to lock the selected operating point.

In the example below, the curve has drifted, and the optical modulated signal is seriously affected in both amplitude and frequency if the bias voltage is not corrected.

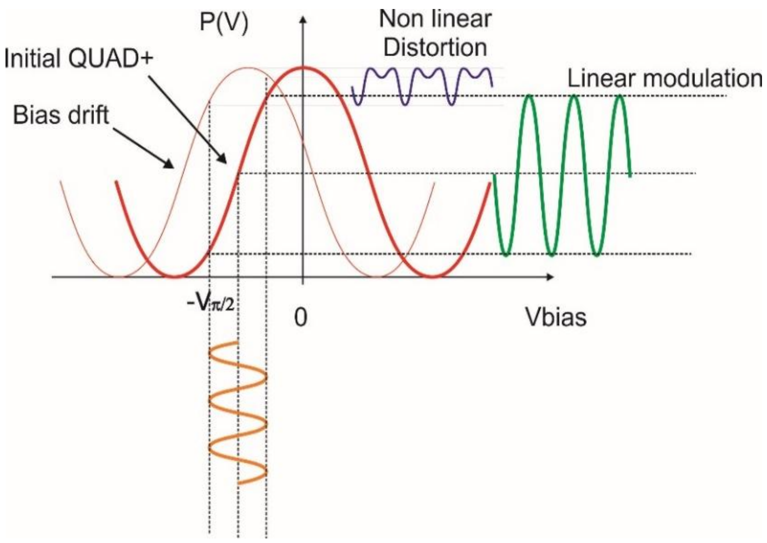

Figure 7: A drift of the modulator transfer function results in a change of the optical modulated signal if the bias voltage is not adjusted accordingly.

Exail solutions

Exail offers a choice of MBC (Modulator Bias controller) solutions which are bench-top instrument:

- MBC-DG-LAB and board MBC-DG-board that can work for most of the applications: it can select and lock the modulators at all its different points. See MBC-DG datasheet.
- MBC-AN-LAB and board MBC-AN-board that are designed for the analog applications: it selects and locks the QUAD+ and QUAD- points of the modulators. The main difference with the MBC-DG is that it does not rely on a dither signal. See MBC-AN datasheet.
- MBC-IQ-LAB and board MBC-IQ-board that can select and lock the operating point of Mach-Zehnder modulators when working with the MXIQ modulator serie. See MBC-IQ datasheet.

Figure 8: MBC-DG-LAB bench top bias controller

Response of the modulator with a MBC

The optical power transmitted by the Mach-Zehnder modulator is first expressed by considering a sinusoidal RF modulation:

$$P = \frac{P_o}{2}[1 + cos(\alpha_{dither}\, sin\, \Omega_{dither}\, t + \beta_{RF}\, sin\, \omega_{RF}\, t - \varphi)]$$

α_{dither} and β_{RF} represent the modulation indices of the dither and RF pulsation signals Ω_{dither} et ω_{RF} respectively and ϕ is the bias phase shift.

We can develop the cos-term:

$$P = \frac{P_o}{2}[1 + cos(\alpha_{dither}\, sin\, \Omega_{dither}\, t + \beta_{RF}\, sin\, \omega_{RF}\, t)\, cos\, \varphi \\ + sin(\alpha_{dither}\, sin\, \Omega_{dither}\, t + \beta_{RF}\, sin\, \omega_{RF}\, t)\, sin\, \varphi]$$

Only the low-frequency components of the signal received by the monitoring photodiode are considered. This is a small signal, so we only consider the first orders of development. Thus, by frequency filtering using a low-pass filter, the high frequency terms are filtered ω_{RF}, $2\omega_{RF}$, $3\omega_{RF}$, $4\omega_{RF}\dots$

There are still low frequency terms related to the modulation of the dither:

$$P = \frac{P_o}{2}\left[1 + \left(J_0(\beta_{RF})\right)[cos(\alpha_{dither}\, sin\, \Omega_{dither}\, t)\, cos\, \varphi + sin(\alpha_{dither}\, sin\, \Omega_{dither}\, t)\, sin\, \varphi]\right]$$

We thus show that whatever the value of the bias, the amplitude of the harmonics Ω_{dither} and $2\Omega_{\mathrm{dither}}$, which respectively define the MAX/MIN and QUAD+/QUAD- modes of the MBC, is affected by the term $J_0(\beta_{RF})$, where J_0 is the first order Bessel function. When $J_0(\beta_{RF})$ equals to 0, The MBC no longer has any spectral component to lock on. This is achieved when β_{RF} =2,4. β is here defined by $\beta_{\mathrm{RF}} = \pi.\frac{V_o}{V_\pi}$, where V_o is the amplitude of the modulating RF signal.

Thus, when $V_0 = 2{,}4.\frac{V_\pi}{\pi}$ (i.e. $0{,}76.V_\pi$), the feedback loop cannot operate any longer in stable conditions. In addition, the higher the amplitude of the RF signal, the more it is necessary to increase the amplitude of the dither signal to compensate for its attenuation by the RF signal.

To ensure the correct control of bias, the amplitude of the modulating RF signal must verify the following condition:

$V_o < 0{,}76\ V_\pi$, i.e. a peak-to-peak amplitude of $V_{pp} < 1.52\ V_\pi$

Considering the halfwave voltage to be V_π =6 Volts, then:

$V_o < 4{,}5$ Volts or $V_{pp} < 9$ Volts, of equivalent power P < +23 dBm

Typical setups and Exail components

The MBC is used to select the operating point of the modulator and lock it over time and temperature. Once it is done, and the proper bias voltage is applied and will keep adjust to the DC-drift, one can apply the modulation signal to the modulation electrodes according to the application (see figure 10 to 14). For more detail, see the Technical Note: [TN - Introduction to Exail RF drivers and amplifiers for optical modulators]().

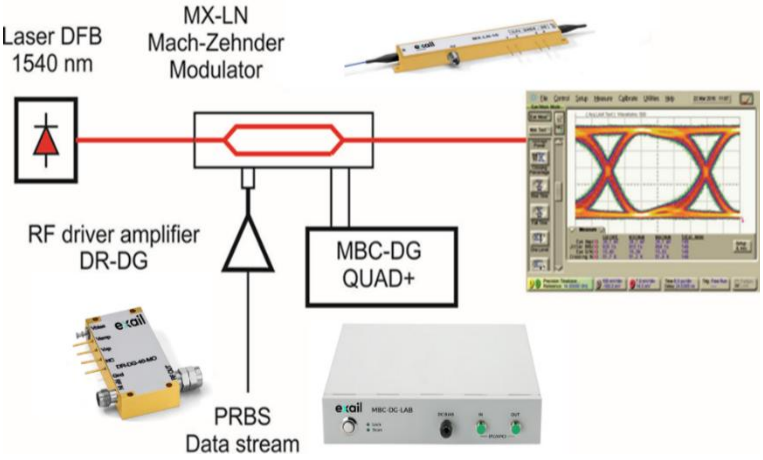

Figure 10: Typical set-up for digital NRZ modulation

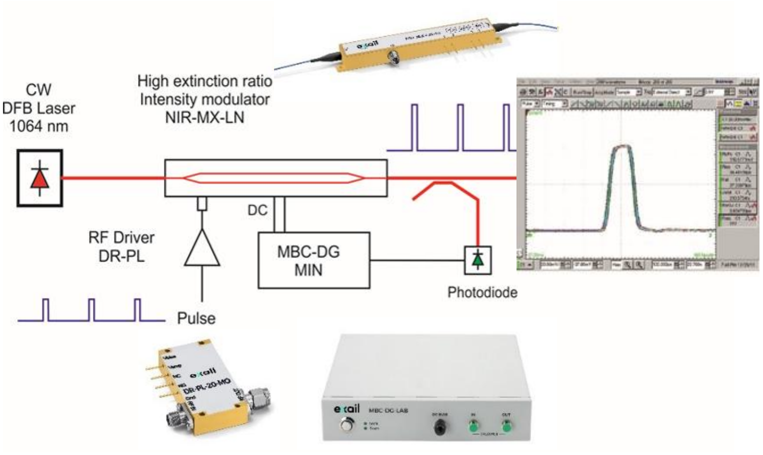

Figure 11: Typical set-up for pulse modulation

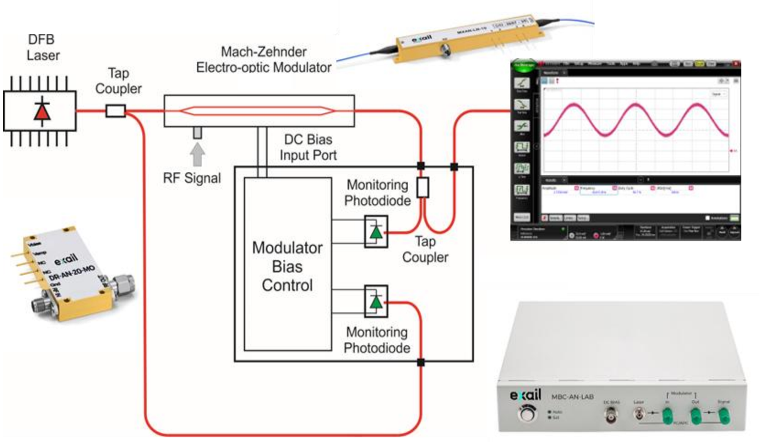

Figure 12: Typical set-up for analog modulation

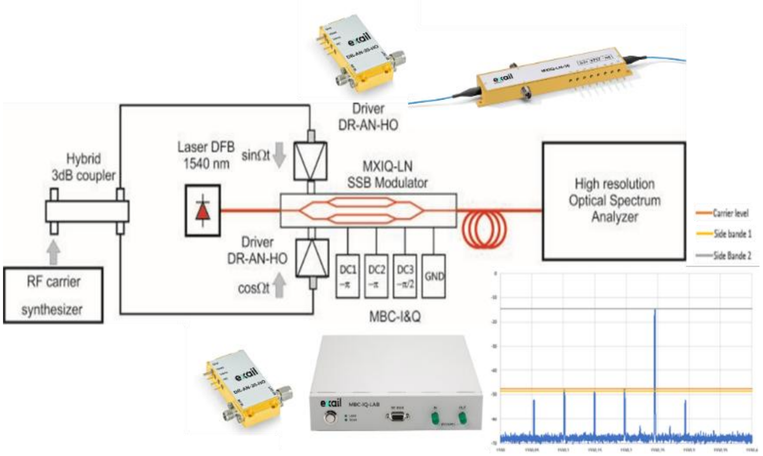

Figure 13: Typical set-up for CS-SSB modulation