DACx1416 Delivers Optimized Solution to Mach-Zehnder Modulator Biasing in Both Ratio- and Dither-type Circuits

Optical line cards and modules demand high-integration and application-specific features for IQ modulator biasing. The DACx1416 is geared to provide a holistic and highly-optimized solution that requires minimal external components. It also addresses the specific requirements of all MZM technologies and biasing topologies.

Optical modulation for speeds beyond 10Gbps has been practically realizable with the use of external modulators popularly known as the Mach-Zehnder Modulator (MZM). A MZM consists of two phase modulators that change the speed of the light passing through them by changing the refractive index of the medium, proportional to an applied electrical signal. When biased at the correct point on the transfer function, this device can be used to combine light beams either constructively or destructively corresponding to 1's and 0's of a binary signal, respectively. A single MZM can thus create simple BPSK (Binary Phase Shift Keying) modulation. However, due to the increasing demands for packing more bits per symbol, modern optical communication uses modulation schemes like DP-QPSK (Dual Polarization Quadrature Phase Shift keying). In order to achieve such sophisticated modulation schemes, four nested pairs of MZM's are required along with 90° phase shifters and polarization rotators, as shown in Figure 1. This is called a nested IQ modulator.

Biasing the MZM

Each phase modulator inside a nested MZM needs to be biased appropriately in order to achieve the desired modulation format. However, this bias point drifts over time from its intended position due to thermal and electrical stress. This leads to degradation in the optical extinction ratio [1] and in turn, the Bit Error Rate (BER). Hence, an active bias control mechanism is invariably required, which finds common implementation in two types: "Ratio-type control" and "Pilot-tone or dither-type control".

Ratio-Type Bias Control [2]: In this method, the optical signal is tapped at both input and output of the MZM and fed to two photodetectors. The bias point is maintained by keeping a constant ratio of current through the photodetectors. Characteristics matching of these photodetectors is the key for optimum performance of such a mechanism.

Pilot-tone or Dither-Type Bias Control: This method uses a small dither tone imposed on to the DC bias input and the optical signal is tapped only at the output to monitor the resulting strength of the dither tone. Due to the complex sinusoidal transfer function of the MZM, the strength of the fundamental frequency of any input signal reaches minima at 'null' and 'peak' bias points, when seen at the output. The DC bias voltage is accordingly adjusted to achieve this target.

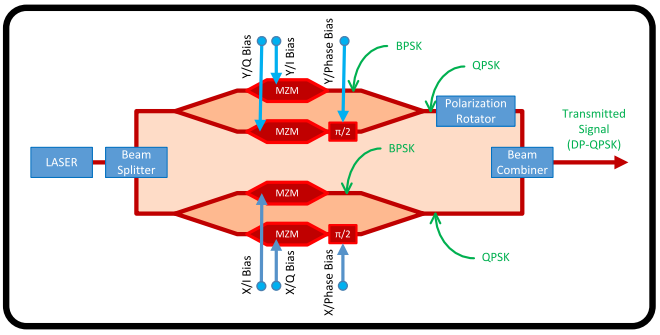

Figure 1. Nested IQ Modulator

Requirements of the Biasing Circuit

Designing biasing circuits that are suitable to match all types of MZM technologies ($LiNbO_3$ and InP) [3] requires high voltage and current ranges as shown in Table 1. The Optical Internetworking Forum (OIF) [4] recommends 4 differential IQ bias and 2 differential phase bias inputs. This differential signaling scheme helps in minimizing the crosstalk and noise between channels, which may otherwise end up complicating the bias control algorithm.

While an ideal dither tone should be a sine wave, generating it can be cumbersome in a largely digital circuit environment. However, a *square wave* [5] that is much easier to generate through digital circuits, can also be used provided that the bandwidth of this dither

(1) Optical Extinction Ratio: Ratio between the optical power corresponding to a binary 1 to that of a binary 0
(2) PSI-0404-11 Ditherless Bias Controller
(3) Comparison of Coherent IQ Modulator Technologies
(4) OIF-HBPMQ-TX-01.0
(5) Hwan Seok et al., "Field trial of automatic bias control scheme for optical IQ modulator and demodulator with directly detected 112 Gb/s DQPSK Signal," Opt. Express 21, 24962-24968 (2013)

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signal is lower than the low-cutoff frequency of the receiver (i.e. 100kHz or 1MHz as per OIF) [6]. Optionally, passive RC filters can be used for limiting the bandwidth further after considering the impact of output current. An additional requirement is to have two orthogonal dither frequency sources for the 'I' and 'Q' arms for smooth detection of the dither signal at the modulator output.

Table 1. Requirements of MZM Biasing Circuit

Parameter	Value
DC Range	Up to ±18V
Dither Amplitude	40mV to 500mV
Dither Frequency	100Hz to 100kHz
Dither Shape	Sine or square
Bias Current	Up to 25mA
# of Dither Frequencies	2
Output Type	Differential (6 pairs)

DACx1416 Family of Precision DAC's

The DACx1416 is a 16-channel buffered voltage output precision DAC available in 16-, 14- and 12-bit variants. It has an integrated reference with 10 ppm/°C drift. The outputs can scale up to ±20V in bipolar and +40V in unipolar modes with multiple range options. The 16-channels can be configured as 8 differential pairs with configuration option available for each pair. The output current can provide up to 25mA for resistive loads. In addition, this DAC features a toggle mode with multiple inputs to easily generate a square wave of a programmable amplitude at the output that can be superimposed onto a variable DC value. This device comes in a 6mm x 6mm QFN package that is favorable for PCB level thermal management.

A block diagram of the dither-type biasing circuit implementation is shown in Figure 2.

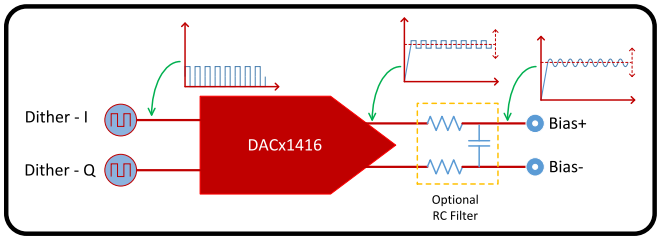

Figure 2. Using DACx1416 for Bias Generation

Table 2 provides the relationship between the output current and INL with the requirement of minimum power supply headroom. Please note that DACx1416 provides an absolute accuracy of > 14 bits even at 25 mA load.

Table 2. Output Current vs INL

Output	Min. Headroom	INL (LSB @ 16-bit)
±15 mA	±1 V	0.133
±20 mA	±1.5 V	0.25
±25 mA	±2.5 V	2.6
±25 mA	±3 V	2

Figure 3 depicts the waveform at the DAC output for a 10kHz dither riding on a 15V DC value and the corresponding frequency spectrum. Please note that the effective bandwidth of this signal is well within 100kHz at both DAC output and at the output of the RC low-pass filter.

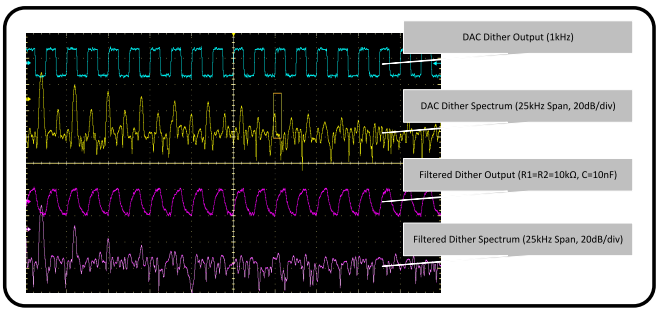

Figure 3. DACx1416 Output Waveform

Competition and Take Away

There are a couple of offerings from the competition targeting the MZM biasing application: some provide similar features as that of DACx1416 while some others provide sine wave dither tone option. However, none of them meet the requirements specified in Table 1 holistically and hence, fail to provide an optimized solution for this application. In fact, the features like differential output, high voltage and current ranges are completely missing in the competitor devices, which will in turn ask for ad-hoc implementations such as software-based pseudo-differential output and inclusion of external amplifiers for high-voltage and high-current outputs. Few devices even miss an internal reference leading to increased footprint of the solution.

The feature-loaded DACx1416 family of devices has been specifically designed to suit MZM biasing application requirements in both ratio-type and dither-type implementations. These devices require minimal external components with the help of features such as internal reference, high-voltage, high-current and differential output. Equipped with high-integration, small size and application-specific features, the DACx1416 family is a perfect candidate for IQ modulator biasing that is applicable for both optical line cards and optical modules (line-side and client-side), compatible with different MZM technologies and is much ahead of what the competition offers.

[6] OIF-DPC-RX-01.2, OIF-DPC-MRX-02.0

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