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.

Requirements of the Biasing Circuit

Designing biasing circuits that are suitable to match all types of MZM technologies (LiNbO₃ 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
signal is lower than the low-cutoff frequency of the receiver (i.e. 100kHz or 1MHz as per OIF) \(^\text{(6)}\). 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

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

Table 2. Output Current vs INL

<table>
<thead>
<tr>
<th>Output</th>
<th>Min. Headroom</th>
<th>INL (LSB @ 16-bit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>±15 mA</td>
<td>±1 V</td>
<td>0.133</td>
</tr>
<tr>
<td>±20 mA</td>
<td>±1.5 V</td>
<td>0.25</td>
</tr>
<tr>
<td>±25 mA</td>
<td>±2.5 V</td>
<td>2.6</td>
</tr>
<tr>
<td>±25 mA</td>
<td>±3 V</td>
<td>2</td>
</tr>
</tbody>
</table>

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 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.

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 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
IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ("TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, “TI Resources”) are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT. AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include, without limitation, TI’s standard terms for semiconductor products (http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2018, Texas Instruments Incorporated