Characterization of the Bias Current Behavior in a SOA for Linearizing Amplification in a CO-OFDM System

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Abstract: This paper presents an analysis of the semiconductor optical amplifier (SOA) on coherent optical orthogonal frequency division multiplexing system (CO-OFDM), when it is used as a booster power amplifier. The semiconductor optical amplifier is driven by their bias current injection, which control the amplification level. In this sense, this study analyses the impact of bias current change on a SOA based CO-OFDM system. It is well known that SOA is prone to nonlinear distortion when high input power is used at high gain level, because the gain saturation. In addition to the aforementioned analysis, here it is also presented three operation scenarios to characterize the performance of the system: maximum EVM equal to 20%, constant output power equal to -7 dBm, and constant SOA Gain equal to 17 dB. This let us obtain a way to optimize the SOA performance, under each scenario, controlling the bias current.

1 INTRODUCTION

Amplification process is a crucial step in the coherent optical orthogonal frequency division multiplexing (CO-OFDM) systems. Given the inherent nature of the CO-OFDM signal to generate high peaks of signal, it condition could drive the optical amplifier to gain saturation, and signal distortion at the receiver (Rahmatallah, 2013). Because of it, the optical amplifiers are one of the key components in the CO-OFDM systems (Khaleghi, 2013). Recently the semiconductor optical amplifiers (SOA) has been extensible studied as a good candidate in CO-OFDM systems, due to the cost-effective characteristics (Azou, 2015), (Renaudier, 2019). However, SOA still have some points to solve, for instance, SOA can exhibit nonlinear behavior when it operates in saturation region. These nonlinearities can cause problems such as frequency chirping and generation of inter-modulation products (Bendimerad, 2017). One way to avoid these undesirable effects is to regulate dynamically the bias current (I_{bias}) to control de SOA amplification, in order to avoid SOA gain saturation.

The principal application of SOA can be divided in three main functions: power booster of transmitter, in line amplifiers, and optical preamplifier. The booster amplifiers are placed at the optical transmitter side to enhance the transmitted power level or to compensate for the losses of optical elements between the laser and optical fibers, such as optical couplers, and external optical modulators. In-line amplifiers are placed along the transmission link to compensate the losses incurred during propagation of optical signal. Optical preamplifiers are used to increase the signal level before photo-detection occurs, improving the receiver sensitivity (Shieh, 2010).

This study aims to analyze the impact of bias current change in the SOA behaivor, used as a booster for a back-to-back CO-OFDM transmission. To achieve this goal, we use a simulation system based on Matlab for digital signal processing of modulation-demodulation, and ADS for the SOA model simulation. This simulator has been used before in (Khaleghi, 2013), (Younes, 2017) showing good consistence between simulation and experimental results.

The rest of this report is organized as follows. Section II presents the simulation results given by the bias current change on SOA based CO-OFDM system for a wide range of input power (P_{in}) levels. In Section III we go into the analysis of bias current functions to

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control the EVM, output power (P_{out}) or optical gain (Gain), also we analyzed the benefits and disadvantages of these three approaches. Section IV gives the conclusions of this study.

2 BIAS CURRENT CHANGE IN SOA

As mentioned before, we simulate a back to back CO-OFDM transmission, using the SOA as a booster amplifier, as seen in Figure 1. The system was simulated with 128 subcarriers, 4 QAM baseband modulation, electrical bandwidth of 5 GHz, and an oversampling factor os = 4.

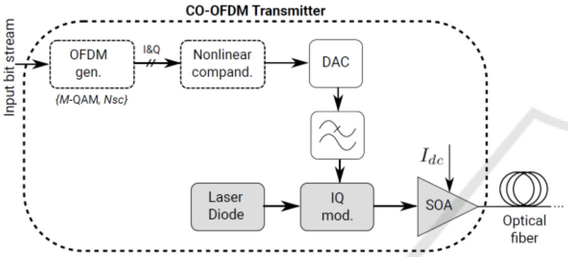


Figure 1: A SOA as a booster amplifier in a CO-OFDM transmitter.

The objective of the simulation is to characterize the impact of the SOA bias current I_{bias} on three main aspects of its behaviour as amplifier within a CO-OFDM system: gain (G), output power (P_{out}), and error vector magnitude, (EVM). All this under different conditions of the input power P_{in}. To achieve this goal, we measured the aforementioned variables for a range of different input powers, from -31 dBm to -6 dBm, in steps of 1 dBm. For each test point, we variates the bias current from 65 mA to 315 mA in intervals of 1 mA. This gives a total of 6526 tests. These values have been chosen in order to include the linear and nonlinear SOA operation.

2.1 EVM Function of P_{in} and I_{bias}

First, we run simulations to obtain the behavior of the EVM for variations of the bias current and the input power. Figure 1 shows graphically the results. Here we can observe that the way EVM changes when the input power and the bias current increase. The EVM rises rapidly for high values of I_{bias} and P_{in}. For example, the system can get up to 40 % EVM for a P_{in} equal to -16 dBm for values of I_{bias} of 345 mA.

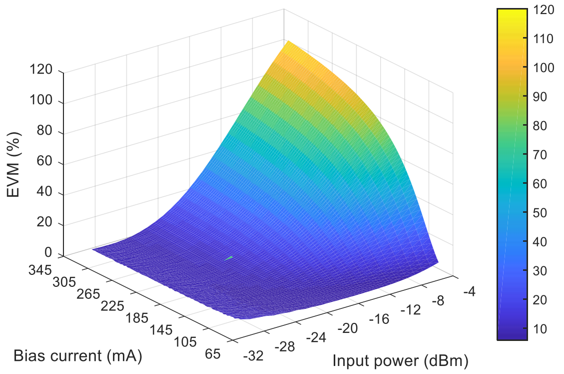


Figure 2: EVM function of P_{in} and I_{bias} in CO-OFDM system with SOA as booster amplifier.

2.2 P_{out} Function of P_{in} and I_{bias}

The simulations for obtaining the behavior of the output power, related to variations of the bias current and the input power, produced the results shown in Figure 2. As already known (Saleh, 1988), the output power level of the amplifier, for a specific input power value, can be controlled by selecting the right bias current. As a reference, for an input power of -16 the amplifier can produced around 5 dBm at its output for a EVM of 40% when using a I_{bias} of 345 mA. Both figures allow us to have a broad view of the behavior of the amplifier for different conditions.

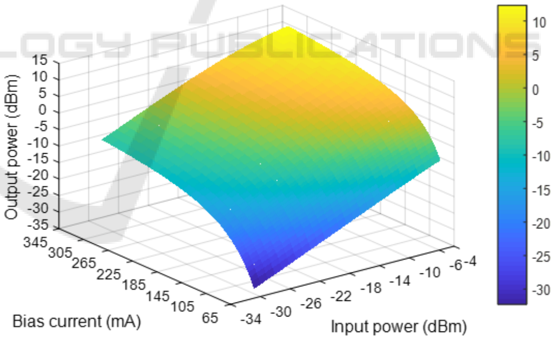


Figure 3: SOA output power function of P_{in} and I_{bias}.

2.3 Gain Function of P_{in} and I_{bias}

Figure 3 illustrates the behaviour of the amplifier's gain. We can clearly see the direct dependence of the gain of the amplifier with respect to the current. Here, the maximum gain is obtained for low input powers. For example, the amplifier's gain is 22 dB for an input power of -28 dBm. On the contrary, there is a reduction of the gain for high input powers.
Figure 5 shows the gain curves versus bias current and input power with more detail. It is clearer

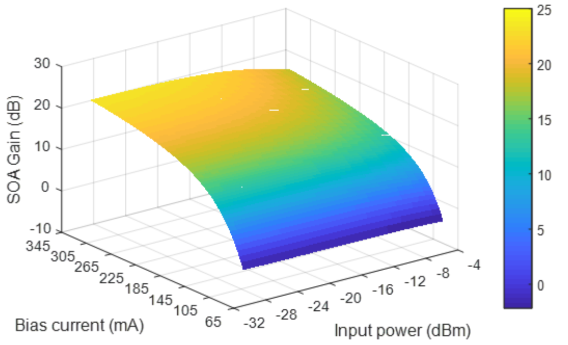


Figure 4: SOA Gain function of P_{in} and I_{bias}.

observed the gain reduction as the input power increases for a constant bias current.

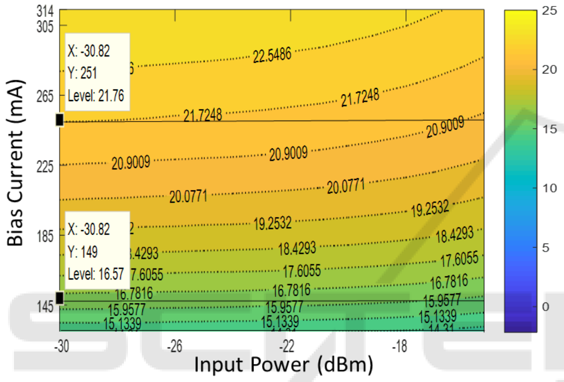


Figure 5: Detail of SOA Gain function of P_{in} and I_{bias}.

2.4 Bias Current for Minimum EVM

We are interested in characterizing the behavior of the SOA under certain conditions. One condition is to obtain the minimum possible EVM regardless of the value of the input power. We want to know what current to use to achieve this.

We can get a model from each result of the EVM obtained in subsection 2.1 for each input power value. As an example, Figure 6 shows the curves of the EVM function the bias current for two different input powers: -22 dBm and -17 dBm. Using a MATLAB fitting function we obtain the polynomials described in equations (1), for -22 dBm,, and (2), for -17 dBm.

$$EVM(I_{bias}) = -0.13I_{bias}{}^5 + 0.4I_{bias}{}^4 + 1.3 \times 10^{-4} I_{bias}{}^3 + 1.4I_{bias}{}^2 + 4.2I_{bias} + 18.5 \qquad (1)$$

$$EVM(I_{bias}) = -0.7I_{bias}{}^7 + 0.14I_{bias}{}^6 - 0.9I_{bias}{}^5 + 0.4I_{bias}{}^4 + 2I_{bias}{}^3 - 4.7I_{bias}{}^2 + 9.7I_{bias} + 28.6 \qquad (2)$$

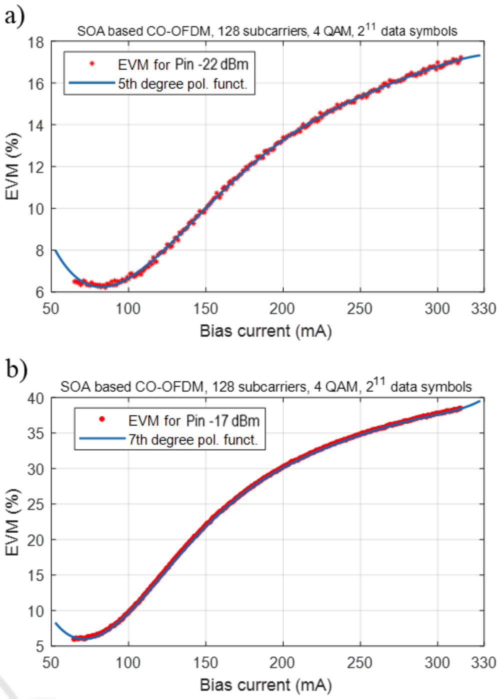


Figure 6: EVM function of P_{in} and I_{bias} for two different input powers.

The next step to obtain a model for all input powers, is to search the minimum EVM of each single-variable polynomial function by using a constrained variable I_{bias} as follows:

$$\arg\min_{I_{bias}} EVM(I_{bias}) \qquad 65mA \leq I_{bias} \leq 315mA \qquad (3)$$

We applied linear regression to obtain the model described by equation (4). This equation shows what is the bias current needed to obtain the minimum EVM for a given input power. The curve of such a function is illustrated in Figure 7.

$$I_{bias}(P_{in}) = -2.6P_{in}{}^9 + 4.91P_{in}{}^8 + 9.51P_{in}{}^7 - 15P_{in}{}^6 - 18P_{in}{}^5 + 18.52P_{in}{}^4 + 12.23P_{in}{}^3 + 4.72P_{in}{}^2 - 20.5P_{in} + 71.59 \qquad (4)$$

We run a test in the simulator of the CO-OFDM system using the previous function. We introduced a signal with different input powers, for each power we used a different bias current, calculated with the equation (4) and we computed the EVM of the received signal. Figure 8 shows the results (variable bias) comparing it with those obtained with a fixed current. In this case value of the current is 150 mA.

The observation of parallel results of the simulations let us find that the cost of minimizing the

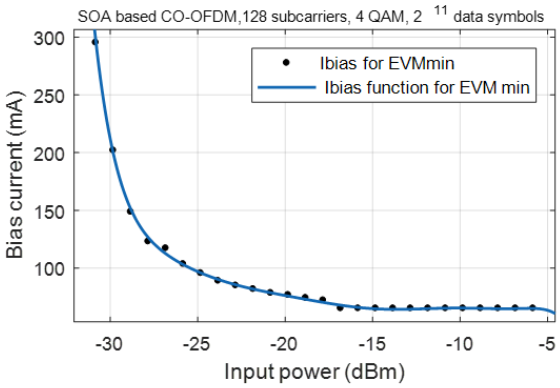


Figure 7: Bias current function of P_{in} and I_{bias} to obtain the minimum EVM.

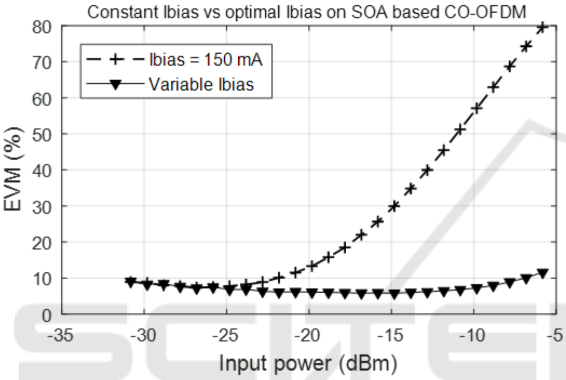


Figure 8: EVM function of P_{in} applying bias current corresponding to each power level to obtain minimum error.

error is forcing a decrease in output power, originated by decreasing the gain. This is expected, since the decrease in current decreases the gain of the amplifier. Both behaviors are shown in Figure 9 and Figure 10. This model allows us to know exactly how the amplifier behaves controlling the current to achieve the smallest EVM depending the input power.

The search of minimal EVM by controlling I_{bias} drives the SOA to a Gain depletion and Pout attenuation. In such a case, a good profile of bias to get a sufficient gain with a certain acceptable level of distortion at the receiver (EVM) is needed.

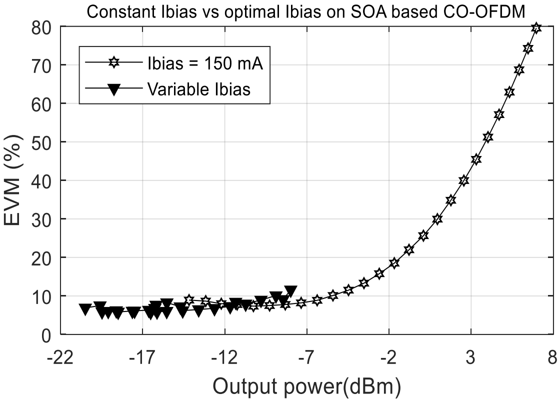


Figure 9: Output power response when bias current change for minimum EVM and Pout curve when bias current is constant 150 mA, It drives CO-OFDM system to a amplification fail above Pin = -18 dBm.

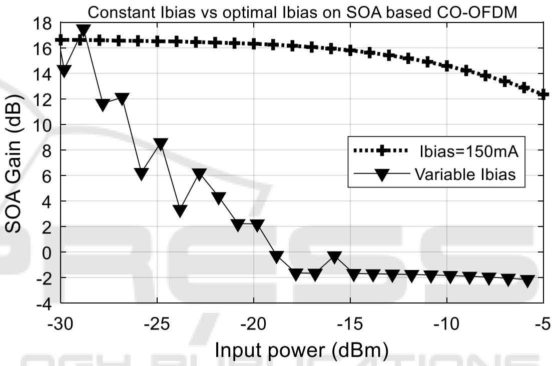


Figure 10: EVM function of P_{out} applying bias current corresponding to each power level to obtain minimum error.

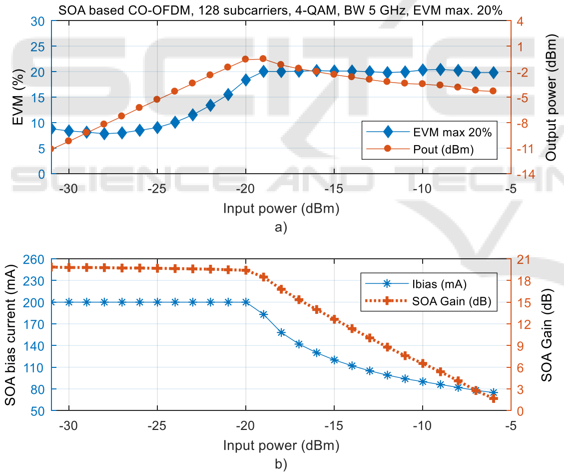
3 IMPACT OF BIAS CURRENT ON SOA PERFORMANCE

From the previous results, it is clear that it is necessary to find a good trade-off between EVM and P_{out} to have a good operational level in amplification terms. Therefore, we propose three different profile behaivors to analyse the impact of the bias current on the SOA.

The first profile is obtained under the condition of keeping the EVM at a maximum of 20%. The second profile consists in preserving a constant P_{out} equal to -7 dBm. The third scenario to investigate is for a constant SOA Gain of 17 dB over the whole P_{in} range analysed previously. We search in the results obtained in the previous section: EVM, P_{out} and Gain function of I_{bias} and P_{in}, for the values of I_{bias}, for each value of P_{in}, that fits the conditions of each of the aforementioned profiles. From these values, we estimate a linear regression to get I_{bias} functions depending of P_{in}, to control de SOA amplification according to one of the three desired profiles. This can allow, for example, automating the envelope-tracking scheme proposed in (Ortiz, 2017).

3.1 Maximum EVM Equal to 20%

According to the results shown in Figure 2 for EVM function of I_{bias} and P_{in}, we observe that EVM is relatively low, EVM < 20 %, for the linear region $P_{in} < -19$ dBm, so we define an I_{bias} equal to 200 mA to obtain a SOA Gain of 20 dB with low EVM. On the other hand, for high input power, $P_{in} > -19$ dBm, which is the SOA nonlinear region, we define an EVM threshold of 20%, gradually decreasing I_{bias} to keep the EVM equal to 20% for $-19 < P_{in} < -6$. The results are shown in Figure 11. Here, we observe that Pout decreases as a consequence of I_{bias} reduction. Also we can observe the SOA Gain attenuation in accordance with the I_{bias} decrease. Moreover, SOA Gain has a linear decrease, and I_{bias} has a nonlinear decrease.



a)

b)

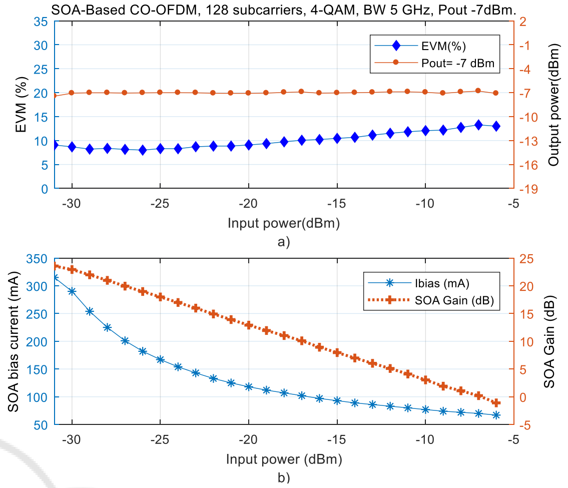
Figure 11: EVM and bias current for a maximum EVM of 20% at different input powers.

We compute from the Ibias current points a linear regression to get an Ibias model. Since the complexity of the Ibias behavior, we use a rational model, which is a polynomial over a polynomial:

$$I_{bias}(P_{in}) = \frac{-2.8{P_{in}}^5 - 145.8{P_{in}}^4 - 1282{P_{in}}^3 + 5.7\times10^4{P_{in}}^2 + 1.4\times10^6 P_{in} + 9.6\times10^6}{{P_{in}}^4 + 77.2{P_{in}}^3 + 2297{P_{in}}^2 - 3.1\times10^4 P_{in} + 1.6\times10^5} \quad (5)$$

3.2 P_{out} Equal to -7 dBm

We search into the results for P_{out} , function of I_{bias} and P_{in}, the bias current values to get P_{out} equal to -7 dBm all along the P_{in} range (from -31 dBm to -6 dBm). The results are shown in Figure 12.



a)

b)

Figure 12: EVM and bias current for a constant P_{out} equal to -7 dBm.

We can see that EVM has values below 15%, even in high P_{in} values. It shows a quasi-linear response. In addition, SOA gain has a linear decrement, this effect reduces SOA gain saturation and, therefore, EVM is low. This condition could be a drawback in the case where we need to have a high gain for a P_{in} above -19 dBm.

The I_{bias} behavior is modeled by a 4th degree polynomial as shown as follows:

$$\begin{aligned} I_{bias}(P_{in}) = 5.6\times10^{-4}{P_{in}}^4 + 53.5 \\ \times 10^{-3}{P_{in}}^3 + 1.9{P_{in}}^2 \\ + 29.53P_{in} + 312.5 \end{aligned} \quad (6)$$

3.3 Constant SOA Gain of 17 dB

In this scenario, we search in the results for Gain, function of Ibias and Pin, obtained in subsection 2.3, the Ibias values needed to keep a SOA gain equal to 15 dB. These values are shown in Figure 10.

This profile shows a clear inconvenient when the P_{in} is higher than -20 dBm: the EVM increases exponentially. This is due to the distortion caused by the amplifier at such ouptut region. We can observe also that the SOA gain has an inverse behavior compared to P_{out} in the second profile.

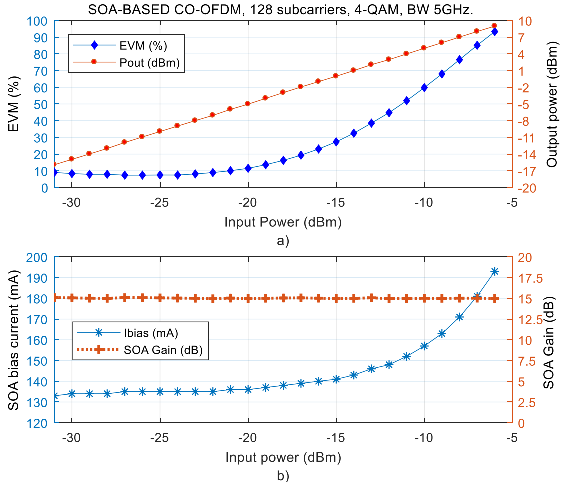


Figure 13: EVM and bias current for a constant SOA gain of 15 dB.

These results can be modelled by a 6th degree polynomial function:

$$I_{bias}(P_{in}) = 2\times10^{-6}{P_{in}}^{5} + 1.5 \times 10^{-3}{P_{in}}^{4} + 73 \times 10^{-3}{P_{in}}^{3} + 1.4{P_{in}}^{2} + 9.5P_{in} + 87.3 \quad (7)$$

4 CONCLUSIONS

The characterization of a SOA used as a booster amplifier in a CO-OFDM system has been presented. We investigated the way the bias current and the input power affects the SOA performance in terms of EVM, output power, and Gain. We demonstrated that a trade-off to obtain a good behavior is needed, depending three different scenarios of operating conditions. We analysed the performance profile and developed a formula to compute the bias current values that fits to each of three scenarios: maximum EVM equal to 20%, constant output power equal to -7 dBm, and constant SOA Gain equal to 17 dB. These formulas would allow to dynamically controlling the bias current to obtain the best results within each operating scenario.

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