SELF-BIAS CONTROL OF ELECTROABSORPTION WAVEGUIDE MODULATOR

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Abstract

For analog fiber optic links using electro-absorption modulators, the correlation between the RF link gain and the modulator photocurrent is investigated both theoretically and experimentally. Based on this correlation, a self-bias control scheme of the electroabs orption modulator for maximum RF link gain is proposed. This scheme can simplify the bias control of modulator arrays.

Introduction

Analog fiber optic links can be used to transmit microwave signals in applications such as cable TV, antenna remoting, and active phased arrays. Semiconductor electroabsorption (EA) modulators are useful in these links in view of their potential for low voltage operation, large bandwidth, and monolithic integration with other components.[1] RF efficiency and spurious free dynamic range (SFDR) are important figures of merit for analog links and are mainly limited by the modulator. For EA modulators, the RF efficiency and the multi-octave SFDR can be optimized at the same modulator bias.[2] However, the optimum modulator bias needs to be adjusted during operation, as the transfer characteristics can change in response to changes in ambient temperature, polarization, and optical power levels. Figure 1 shows a conventional modulator bias control scheme, in which a coupler is used to tap off a portion of the modulated light for examining the RF signal so that the optimal bias can be maintained. However, for modulator arrays, it is highly desirable to employ an approach which can reduce the number of optical components in view of space and fiber alignment considerations.

In this work, we report a novel and greatly simplified approach to control the modulator bias, as depicted in figure 2, which is based upon the correlation between the RF link gain and the modulator photocurrent. We show that, under various operating conditions, the modulator bias at which the modulator photocurrent experiences the largest change with incremental bias tracks closely the bias for the maximum RF link gain. Therefore, using the modulator photocurrent, we can find the optimal modulator bias for maximum RF link gain and multi-octave SFDR.

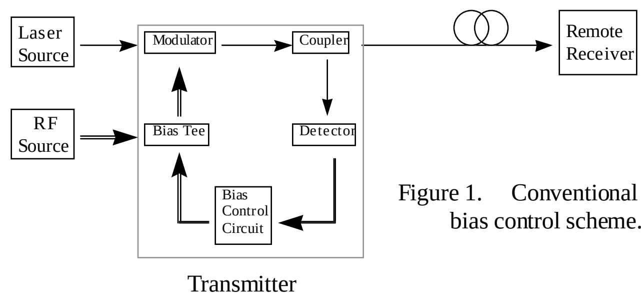

Figure 1. Conventional bias control scheme.

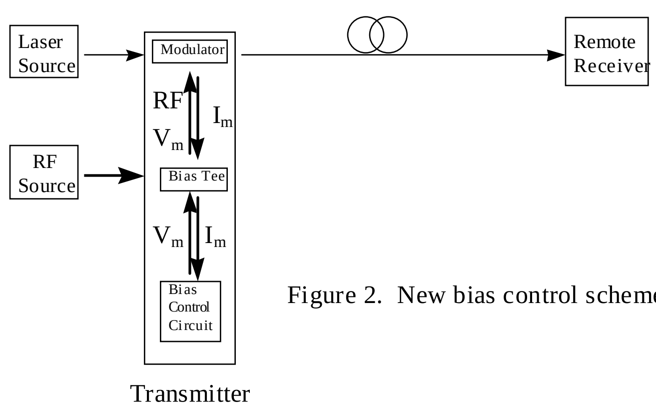

Figure 2. New bias control scheme

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Theory

The above mentioned bias coincidence comes from the correlation among the RF link gain, the modulator transfer curve and the modulator DC photocurrent. The RF link gain is proportional to the square of the slope efficiency of the modulator transfer curve[3], which depicts the modulator transmission versus bias voltage. The modulator transmission is proportional to the modulator absorption, which in turn is proportional to the modulator DC photocurrent. Consequently, the RF link gain is proportional to the square of the change in modulator photocurrent with respect to bias.

The following summarizes the main steps of the derivation.

The total voltage across the modulator is:

$$V = V_m + \nu_m \tag{1}$$

where V_m is the modulator DC bias, ν_m is the AC modulation voltage. For an ideal modulator which can be treated as an open circuit, the RF input power is totally reflected, a standing wave builds up in the input transmission line. Therefore ν_m will be twice the input microwave voltage. The relationship between the input RF power P_{RF-in} and ν_m can be written as:

$$P_{RF-in} = \frac{\nu_m^2}{4R_{in}} \tag{2}$$

where R_{in} is the characteristic impedance of the input transmission line. In practice, since the modulator has a finite impedance, ν_m is less than twice the input voltage. We use a factor ρ_m to account for this modulation reduction effect, and Eq. (2) becomes:

$$P_{RF-in} = \frac{\nu_m^2}{4\rho_m R_{in}} \tag{3}$$

If i_d is the detected AC current at the end of the fiber link, the output RF power right after the detector is:

$$P_{RF-out} = \rho_d i_d^2 R_{out} \tag{4}$$

where R_{out} is the detector output resistance, ρ_d accounts for the RF power loss including the detector impedance mismatch loss. The RF link gain is obtained from the ratio of (4) to (3):

$$G_{RF} = \frac{P_{RF-out}}{P_{RF-in}} = 4\rho_m\rho_d R_{in} R_{out} \left(\frac{i_d}{\nu_m}\right)^2 \tag{5}$$

We obtain i_d/ν_m from the modulator transfer characteristic. The transmission of an EA modulator can be written as:

$$T = S_m L_m^{2} e^{-\Gamma\alpha L} \tag{6}$$

where S_m is the optical loss of the modulator due to scattering; L_m is the loss due to Fresnel reflection and fiber coupling at each facet; Γ is the optical confinement factor of the modulator absorption layer; α is the corresponding absorption coefficient; L is the waveguide length.

The optical power reaching the input facet of the modulator is P_o, and the optical loss from the modulator to the detector (excluding the modulator) is K, the total optical power coupled into the detector is:

$$P_{out} = P_o S_m L_m^2 K e^{-\Gamma\alpha L} \tag{7}$$

With the detector DC current calculated from

$$I_d = \eta_d P_{out} \tag{8}$$

where η_d is the detector responsivity, we obtain

$$i_d = \left(\frac{dI_d}{dV_m}\right)\nu_m$$

$$= -\eta_d P_o S_m L_m^2 K \Gamma L e^{-\Gamma\alpha L} \frac{d\alpha}{dV_m}\nu_m \tag{9}$$

Substituting (9) into (5), the RF gain becomes

$$G_{RF} = 4\rho_m\rho_d R_{in} R_{out} \left(\eta_d P_o S_m L_m^2 K \Gamma L e^{-\Gamma\alpha L} \frac{d\alpha}{dV_m}\right)^2$$

(10)

Next we derive the modulator DC photocurrent I_m. The total optical power absorbed by the EA modulator is:

$$P_{ab} = P_o S_m L_m \left(1 - e^{-\Gamma\alpha L}\right) \tag{11}$$

This gives rise to photocurrent I_m,

$$I_m = \eta_m P_{ab} = \eta_m P_o S_m L_m \left(1 - e^{-\Gamma\alpha L}\right) \tag{12}$$

where η_m is a conversion factor defined as the ratio of the modulator photocurrent to the absorbed optical power. Below saturation η_m is close to e/hν, where e is the Coulomb charge, hν is the photon energy. Taking the derivative of I_m with respect to V_m we get:

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$$\frac{dI_m}{dV_m} = \eta_m P_o S_m L_m \Gamma L e^{-\Gamma\alpha L} \frac{d\alpha}{dV_m} \qquad (13)$$

Combining Eqs. (10) and (13), we get:

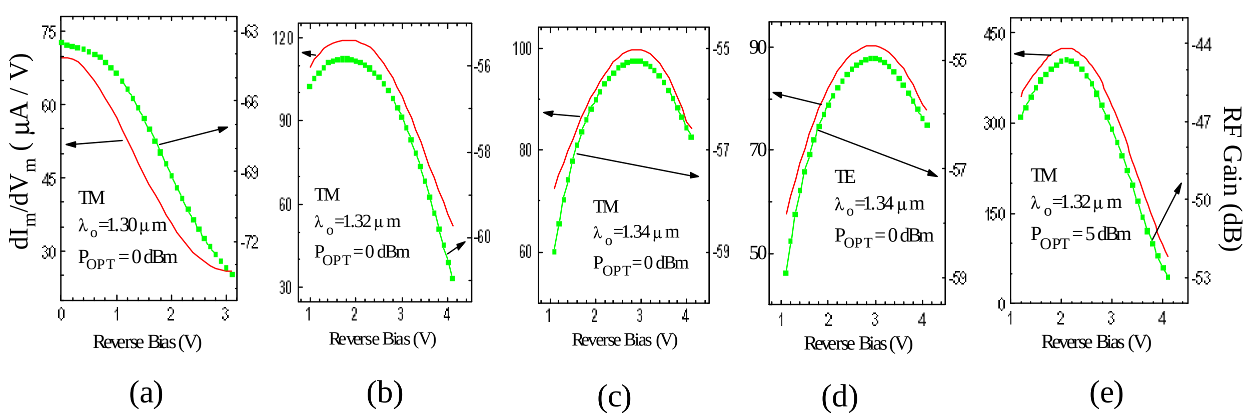
$$G_{RF} = C\left(\frac{dI_m}{dV_m}\right)^2 \qquad (14)$$

where $C = 4\rho_m \rho_d R_{in} R_{out}\left(\frac{L_m K \eta_d}{\eta_m}\right)^2$ (15)

It should be noted in the expression for C that only ρ_m, L_m and η_m have possible dependence on V_m, especially in the case of large optical power coupled into the modulator. At high power, a large density of photo-generated carriers at the absorption region can reduce η_m, especially at small bias.[4] Also the absorption layer dielectric permittivity can change due to the high density of carriers, so that the modulator capacitance and optical mode can be affected. Thus ρ_m and L_m become dependent on V_m at high optical power. However, when optical power is well below the modulator saturation power level, C is essentially a constant, and the bias for maximum G_{RF} coincides with the bias for maximum $|dI_m/dV_m|$. Under this circumstance, the self-bias control scheme in principle works well. When the optical power approaches the modulator saturation level, this bias control method would need modification.

Experiment

An InGaAsP/InP Franz-Keldysh effect waveguide modulator is used in this work. The waveguide has a 2.5 µm thick InGaAsP (λ_Q = 1.26 µm) layer sandwiched between p^+-InP and n^+-InP layers. In the 2.5 µm thick InGaAsP layer, the top 1.15 µm is doped p-type, the middle 0.35 µm is undoped, the bottom 1 µm is doped n-type. Waveguide mesa etching is stopped after etching through the undoped InGaAsP layer. The waveguide mesa is 3 µm wide at the top, and is 180 µm long. This large optical cavity structure is designed to allow a good coupling to lensed fibers. At zero bias, the fiber-to-fiber optical insertion loss at 1.34 µm wavelength is measured to be 8 dB without AR coating. We have also observed polarization insensitive operation for maximum RF gain at this wavelength. (See figures 3c and 3d)



Figures 3a-e G_{RF} versus V_m and dI_m/dV_m versus V_m curves under different operating wavelength, optical power and polarization. In each plot, the left axis is dI_m/dV_m (µA/V), the right axis is RF Gain (dB).

The RF link gain, G_{RF}, and the modulator photocurrent, I_m, are measured as a function of modulator bias voltage V_m. In order to compare the bias point $V_{m\text{-}max}$ (for maximum dI_m/dV_m) with the bias point $V_{RF\text{-}max}$ (for maximum RF gain) under different operating conditions, the measurement were repeated using different laser wavelengths (1.30, 1.32 or 1.34 µm), different

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optical power levels (0 and 5 dBm) and different input polarizations (TE and TM). The ambient temperature change is simulated by laser wavelength change, because the major effect of temperature change is to change the detuning energy of the modulator. A 400 Å wavelength change can represent a temperature change of approximately 80 ^{o}C in this modulator material.

In figures 3a, 3b and 3c, the input light is TM polarized at 0 dBm optical power. The results show that although V_{RF-max} does change substantially for a 400 Å wavelength change, it can be tracked closely by V_{m-max}. Similarly, figures 3b and 3e show that V_{m-max} and V_{RF-max} coincide through the 5 dB optical power change. In figures 3c and 3d, the input light wavelength is 1.34 μm, with 0 dBm optical power. The optimal bias point remains the same when the polarization is switched from TM to TE, so the bias tracking of V_{m-max} and V_{RF-max} is straightforward. These results are summarized in Table 1.

Table 1: Operating conditions and optimal bias points for each measurement in figures 1.

Figure	3a	3b	3c	3d	3e
Wavelength (μm)	1.30	1.32	1.34	1.34	1.32
Polarization	TM	TM	TM	TE	TM
Optical Power (dBm)	0	0	0	0	5
V_{RF-max} (V)	0	1.8	2.9	2.9	2.1
V_{m-max} (V)	0	1.8	2.9	2.9	2.1

We have also conducted measurements at higher optical power and observed that this bias tracking works well up to 13 dBm input for high saturation power devices. We found that V_{m-max} and V_{RF-max} will gradually deviate when the optical power is close to the modulator saturation power level.

Conclusion

We have shown that for an electroabsorption modulator, the bias point V_{m-max} for the largest slope in modulator DC photocurrent with respect to modulator bias, coincides with the bias point V_{RF-max} for achieving the maximum RF link gain. As V_{RF-max} drifts due to changes in operating conditions such as temperature, polarization and optical power levels, it can be tracked by a circuit which determines the bias voltage V_{m-max}. This approach can facilitate the bias control of an electroabsorption modulator for maintaining maximum RF gain in an analog fiber optic link.

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