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Novel Bias Control of Electroabsorption Waveguide Modulator

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Abstract—A novel approach is proposed for controlling the bias of an electroabsorption waveguide modulator for maximum radio-frequency (RF) gain in analog fiber-optic links. It is based upon the correlation between the RF gain and the modulator dc photocurrent. It is found that, under various operating conditions, the modulator bias at which the modulator dc photocurrent experiences the largest change with incremental bias, coincides with the bias for the maximum RF gain. This approach eliminates the need for an external tracking photodiode, and can be useful in bias controls of a modulator array.

Index Terms—Analog fiber link, antenna feeds, communication, modulator.

I. INTRODUCTION

ANALOG fiber-optic links can be used to transmit microwave signals in applications such as cable TV, antenna remoting, and active phased array [1], [2]. 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 [3]. Radio-frequency (RF) efficiency and spurious free dynamic range (SFDR) are important parameters for analog links and are mainly limited by the modulator. For an EA modulator, the RF efficiency and the multioctave SFDR can be optimized at the same modulator bias [4]. 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. Therefore, some method is needed during operation to adjust the bias to maintain maximum RF efficiency and SFDR. A common approach uses a Y-branch coupler inserted after the modulator to tap off a portion of the modulated light for checking the RF signal and thus the optimal bias can be maintained [5]. While this approach can work very well in many cases, it induces extra optical loss including the coupler insertion loss and optical power tapped off by the coupler. A dedicated photodetector is required with this technique. For modulator arrays, it will be desirable to employ an approach which can

reduce the number of optical components to save space and to reduce the number of fiber alignments.

In this letter, we propose a novel approach to control the modulator bias which is based upon the correlation between the RF link gain and the modulator dc photocurrent. We have shown that under various operating conditions, the modulator bias at which the modulator dc photocurrent experiences the largest change with incremental bias, tracks closely the bias for the maximum RF link gain. Therefore, using the photocurrent of the modulator [6], we are able to find the optimal modulator bias for maximum RF link gain. In this approach, the optical configuration is simplified, therefore there is no need to integrate an optical coupler and a photodetector for the tracking purpose.

II. EXPERIMENTAL

An InGaAsP-InP Franz-Keldysh effect waveguide modulator is used in this letter. The waveguide has a 2.5- μm -thick InGaAsP ($\lambda_Q = 1.26 \mu\text{m}$) layer sandwiched between p^+ -InP and n^+ -InP layers. In the 2.5- μm -thick InGaAsP layer, the top 1.15 μm is p-type doped, the middle 0.35 μm is undoped, the bottom 1 μm is n-type doped. 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 device has a good coupling efficiency to lensed fibers due to its large optical cavity structure. At zero bias, the fiber-to-fiber optical insertion loss is measured at 8 dB without AR coating.

An RF fiber link is set up with light fiber-coupled from a laser source to the modulator whose output is fiber-coupled to a detector. A polarization rotator is inserted in the input fiber to control the input light polarization at the modulator. A semiconductor parameter analyzer (HP4145B) is used to set the modulator bias and to measure I_m . A 2-GHz RF signal is applied through a bias tee to the modulator and the RF power from the detector is measured with a spectrum analyzer. The data collection is expedited using a computer controlled acquisition system.

The RF link gain G_{RF} and the modulator dc photocurrent I_m are measured as a function of modulator bias voltage V_m . The dI_m/dV_m versus V_m curve is then derived. In order to compare the bias point $V_{m-\text{max}}$ (for maximum dI_m/dV_m) with the bias point $V_{\text{RF-max}}$ (for maximum RF gain) under different operating conditions, we repeat the measurement using different laser wavelengths (1.30, 1.32, or 1.34 μm), different optical power levels (0 and 5 dBm) and different input polarizations (TE and TM). The ambient temperature change

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Fig. 1. (a)–(e) GRF V_m and dI_m/dV_m V_m curves under different operating wavelength, optical power and polarization. In each plot, the left axis is dI_m/dV_m ($\mu\text{A/V}$), the right axis is RF gain (dB).

TABLE I
OPERATING CONDITIONS AND OPTIMAL BIAS POINTS
FOR EACH MEASUREMENT IN FIG. 1

Figure	1(a)	1(b)	1(c)	1(d)	1(e)
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
$V_{\text{RF-max}}$ (V)	0	1.8	2.9	2.9	2.1
$V_{\text{m-max}}$ (V)	0	1.8	2.9	2.9	2.1

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 °C in this modulator material.

III. EXPERIMENTAL RESULTS

Fig. 1 shows the measured G_{RF} versus V_m and dI_m/dV_m versus V_m curves at different wavelengths [Fig. 1(a)–(c)] and different input polarizations [Fig. 1(c) and (d)] and input optical power levels [Fig. 1(b) and (e)]. Table I lists the operating conditions and corresponding measured optimal bias points $V_{m-\text{max}}$ and $V_{\text{RF-max}}$. To within our measurement resolution of 0.1 V, $V_{m-\text{max}}$ and $V_{\text{RF-max}}$ coincide exactly in all the cases listed.

In Fig. 1(a)–(c), input lights are TM polarized at 0 dBm optical power. The results show that although $V_{\text{RF-max}}$ does change substantially for 400-Å wavelength change, it can be tracked closely by $V_{m-\text{max}}$. Similarly, Fig. 1(b) and (e) show that $V_{m-\text{max}}$ and $V_{\text{RF-max}}$ coincide through the 5-dB optical power changes. In Fig. 1(c) and (d), input light wavelength are at 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 $V_{m-\text{max}}$ and $V_{\text{RF-max}}$ is

straightforward. The polarization insensitivity of this modulator is primarily due to the large optical cavity design of the waveguide, in which the absorption layer confinement factors are close in value for TE and TM modes. Also the Franz–Keldysh electroabsorption change is insensitive to the polarization. This gives a less than 0.3-dB difference between the maximum RF gains shown in Fig. 1(c) and (d).

We have also conducted measurements with high optical power and found that, this bias tracking works well up to 13-dBm optical power for high-saturation power devices. It turns out that $V_{m-\text{max}}$ and $V_{\text{RF-max}}$ will gradually deviate when the optical power is close to the modulator saturation power level.

IV. DISCUSSION

The bias coincidence comes from the intrinsic correlation among the RF 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 [2], which depicts the modulator transmission versus bias voltage. And the modulator transmission is linearly related to the modulator absorption, which is proportional to the modulator dc photocurrent. Consequently, one can derive that the RF link gain is proportional to the square of the slope of modulator dc photocurrent versus bias curve. Analytically, it can be shown that RF link gain G_{RF} is

$$G_{\text{RF}} = C \left(\frac{dI_m}{dV_m} \right)^2 \quad (1)$$

where

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

In (2), the factor of 4 comes from the total microwave reflection by an ideal modulator, which can be considered as an open circuit. This total reflection doubles the modulation voltage and thus gives a factor of 4 for the RF link gain. ρ_m accounts for the modulation reduction due to a finite impedance of the modulator. ρ_d is the RF power loss due to the photodetector impedance mismatch with the load, R_{in} is the characteristic impedance of the modulator input transmission line, R_{out} is the photodetector output resistance, L_m is the modulator optical loss due to reflection and coupling with fiber at one facet, K is the optical loss from modulator to photodetector (not including modulator), η_d is the photodetector dc responsivity, η_m is a conversion factor defined as the ratio of the modulator photocurrent to the absorbed optical power. Before saturation, η_m is close to $e/h\nu$, where e is the Coulomb charge, $h\nu$ is the photon energy. It should be noted that in the expression for C only ρ_m , L_m , and η_m have possible dependence on V_m , especially when a large optical power is coupled into the modulator. At high power, a large density of photogenerated carriers at the absorption region can reduce the η_m , especially at small bias [7]. 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

Fig. 2. A schematic diagram for implementing EA modulator bias control based upon the correlation between RF link gain and modulator dc photocurrent.

below the modulator dc saturation level, C is essentially a constant, so the bias tracking between $V_{m-\max}$ and $V_{RF-\max}$ in principle works well. When the optical power approaches the modulator saturation level, this bias control method would need modification.

This method can also be applied to the case where an impedance matching resistor, R_{sh} , shunts the EA modulator for broadening the modulation bandwidth. The RF link gain expression is then modified by a factor which is voltage independent, leaving $V_{RF-\max}$ unchanged. The current I_{ava} at the voltage source equals the sum of the modulator photocurrent and the shunt current V_m/R_{sh} , which adds a constant to dI_{ava}/dV_m but leaves $V_{m-\max}$ unchanged.

Fig. 2 depicts a schematic diagram for implementing this approach of modulator bias control. During the bias tracking period, the processor will control the voltage sweep to the modulator, collect the modulator dc photocurrent, find the bias point $V_{m-\max}$, and reset the operating bias of the modulator to this voltage.

V. CONCLUSION

We have shown that for an EA modulator, the bias point $V_{m-\max}$ for the largest slope of modulator dc photocurrent versus modulator bias coincides with the bias point $V_{RF-\max}$

for achieving the maximum RF link gain. As $V_{RF-\max}$ drifts in response 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. Comparing with the conventional bias control method, this new approach has advantages of simplicity and space savings, which can be important for modulator arrays.

The approach will need modification when the modulator saturates at high power. However, from an RF efficiency point of view, it is also desirable to develop high-saturation power modulators.

REFERENCES

- [1] W. L. Glomb, Jr., "Fiber optic links for antenna remoting," in *Proc. SPIE, Optical Technology for Microwave Application VI and Optoelectronic Signal Processing for Phased-Array Antennas III*, 1992, vol. 1703, pp. 523-527.
- [2] S. A. Pappert, S. C. Lin, R. J. Orazi, M. N. McLandrich, P. K. L. Yu, and S. T. Li, "Broadband electromagnetic environment monitoring using semiconductor electroabsorption modulators," in *Proc. SPIE, Optical Technology for Microwave Applications V*, 1991, vol. 1476, pp. 282-293.
- [3] N. M. Froberg, G. Raybon, A. M. Johnson, Y. K. Chen, T. Tanbun-Ek, R. A. Logan, A. Tate, A. M. Sargent, K. Wecht, and P. F. Sciortino, Jr., "Pulse generation by harmonic modulation of an integrated DBR laser-modulator," *Electron. Lett.*, vol. 30, pp. 650-651, 1994.
- [4] C. K. Sun, S. A. Pappert, R. B. Welstand, J. T. Zhu, P. K. L. Yu, Y. Z. Liu, and J. M. Chen, "High spurious free dynamic range fiber link using a semiconductor electroabsorption modulator," *Electron. Lett.*, vol. 31, pp. 902-903, 1995.
- [5] G. E. Betts, C. H. Cox, III, and K. G. Ray, "20 GHz optical analog link using an external modulator," *IEEE Photon. Technol. Lett.*, vol. 2, pp. 923-925, 1990.
- [6] R. B. Welstand, S. A. Pappert, C. K. Sun, J. T. Zhu, Y. Z. Liu, and P. K. L. Yu, "Dual-function electroabsorption waveguide modulator/detector for optoelectronic transceiver applications," *IEEE Photon. Technol. Lett.*, vol. 8, pp. 1540-1542, 1996.
- [7] J. Harari, G. Jin, J. P. Vilcot, and D. Decoster, "Theoretical study of p-i-n photodetectors' power limitations from 2.5-60 GHz," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 1332-1336, 1997.