Linearity Characterization of Connectorized Laser Diodes Under Microwave Intensity Modulation by AM/AM and AM/PM Measurements

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Abstract

Measurements and analysis of the AM/AM and AM/PM characteristics of microwave intensity modulated GaAlAs laser diodes with multimode pigtails and biconic connectors have been carried out. In general, AM/AM is the main nonlinearity distortion for a connectorized laser diode. However, AM/PM distortion may become comparable with or dominant over AM/AM distortion when the modulation frequency is close to the resonance region of the laser diode.

Introduction

Measurement of gain compression (AM/AM) and phase deviation (AM/PM) is a well-known method of charaterizing the linearity of microwave devices and systems [1-8]. Methods of charaterizing semiconductor laser diode linearities in the past include (1) examining the linearity of the CW light-current (L-I) curve, and (2) measuring intermodulation and harmonic products. However, the former approach may not give reliable indications of performance above 1 GHz [9]; and the latter does not provide a means of distinguishing between gain and phase distortion. In this paper, measurement techniques and analytical methods are developed to characterize the behavior of semiconductor laser diodes under multi-gigahertz intensity modulation to differentiate the effects of AM/AM and AM/PM, The results show that in general AM/PM is proportional to AM/AM, but the major cause of third-order intermodulation is AM/AM distortion. This suggests that improvement in the AM/AM transfer characteristic may reduce third-order intermodulation products . However, if the modulating frequency is close to the laser resonance region , AM/PM distortion may become the dominant factor for small amplitude input signals. Under these circumstances, the susceptibility of the laser diode to reflection noise from connectors is the main stimulus for increased AM/PM distortion. When stringent phase linearity is a system performance objective, connectorized laser diodes should not be operated at frequencies near the resonance peak.

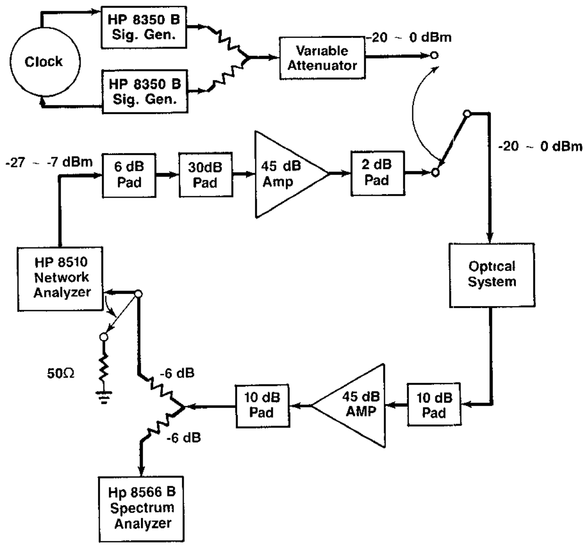

Figure 1 Experimental setup for measuring AM/AM and AM/PM. Under the same operating conditions of the optical system, third-order intermodulation products were measured with two signal generators.

Measurement

The setup for AM/AM, AM/PM, and intermodulation measurements is shown in Fig.1. The input microwave power from the HP 8510 network analyzer was adjusted to sweep a power range of 20 dB at a selected frequency. Attenuators were inserted as needed to prevent amplifier gain compression. The optical system is a back-to-back high-speed GaAlAs laser diode (Ortel LDS10- PMF) and PIN diode (Ortel PD050-PM), both with 1 meter multimode pigtails and biconic connectors. Micro-positioners and index matching fluid were used to minimize reflection noise (observed with a HP 8566B spectrum analyzer). Two laser diodes were used: laser#1 had a threshold current of 19.5 mA and saturated around 70 mA; laser#2 had a threshold current of 17 mA and saturated around 35

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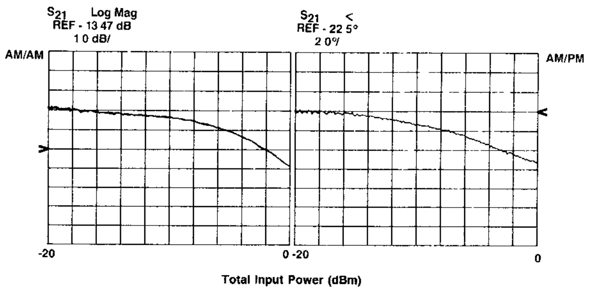

Figure 2 AM/AM and AM/PM characteristics for laser#1 biased at 25.4 mA. Threshold current of this laser is 19.5 mA. The modulating microwave frequency is 2 GHz and the input power swept from -20 to 0 dBm. The small signal resonance under this bias condition is 1.3 GHz. Detected DC photocurrent is 145 μA.

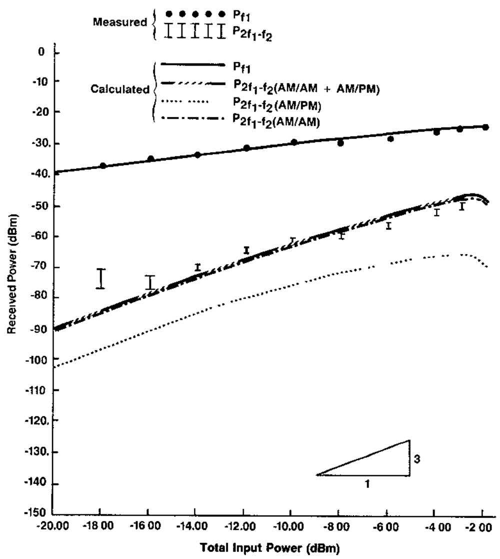

Figure 3 Dots and bars are the measured power levels of fundamental carrier (P_{f_1}) and third-order intermod ($P_{2f_1-f_2}$) under the same operating conditions as in Fig.2. Calculated P_{f_1} and $P_{2f_1-f_2}$ are shown as solid lines. Calculated $P_{2f_1-f_2}$ due only to the effect of AM/AM (broken line) or AM/PM (dashed line) are also shown. The third-order intermod power in general did not rise as the cube of the input power.

mA. Fig.2 shows the AM/AM (dB/dBm) and AM/PM (degrees/dBm) measurement results for laser#1 biased at 25.5 mA (small signal resonance around 1.3 GHz) and modulated by a 2 GHz sinusoid sweeping from -20 to 0 dBm. The maximum gain compression of about 3 dB and maximum phase deviation of about 5° occurred at 0 dBm input (current amplitude 6.3 mA). For the intermodulation tests, a combination of two equal amplitude tones 20 MHz apart (2.0 and 2.02 GHz) were varied over a 20 dB range. Fundamental and third-order intermodulation levels, measured on the spectrum analyzer, are shown as solid dots and bars in Fig.3. For the two-tone measurement, the third-order intermodulation power levels were not dependent on whether the input signals were in-phase or incoherent.

For this laser modulated by a 500 MHz sinusoid (far below resonance) under the same bias level, observations were very similar to those shown in Fig.2 and Fig.3. Sensitivity of AM/AM and AM/PM distortion to laser resonance was investigated by selecting an input frequency close to the resonance peak. As the bias level was increased to 31.5 mA, a small signal resonance peak was observed around 3 GHz. Both AM/AM and AM/PM performance changed significantly (about 4 dB gain compression and 20° phase deviation at 0 dBm input) as shown in Fig.4. Strong reflection noise was also observed around 3 GHz.

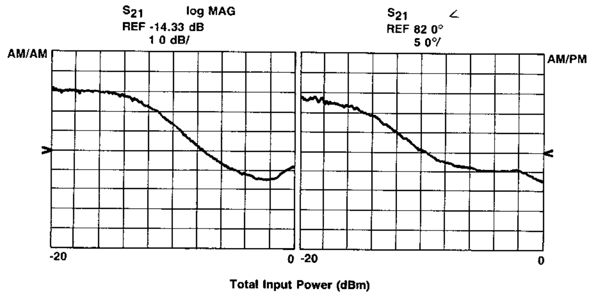

Figure 4 AM/AM and AM/PM characteristics for laser#1 biased at 31.5 mA. Threshold current of this laser is 19.5 mA. The modulating microwave frequency is 3 GHz and the input power swept from -20 to 0 dBm. The small signal resonance frequency under this bias condition is 2.9 GHz. Reflection noise around 3 GHz was high. Detected DC photocurrent is 425 μA.

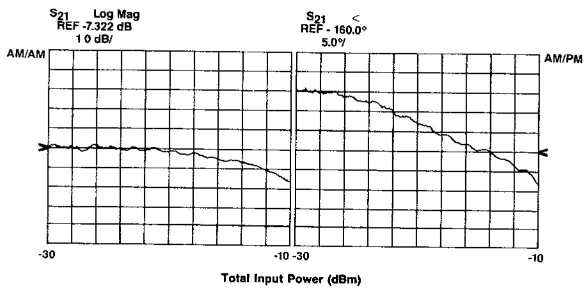

Figure 5 AM/AM and AM/PM characteristics for laser#2 biased at 30 mA. Threshold current of this laser is 17 mA. The modulating microwave frequency is 2 GHz and the input power swept from -30 to -10 dBm. The small signal resonance frequency under this bias condition is 1.95 GHz. Reflection noise was high around 2 GHz. Detected DC photocurrent is 303 μA.

Increased sensitivity of AM/PM to reflection noise around the resonance peak was also observed for laser#2. The results are shown in Fig.5 where the laser was biased at 29.5 mA (small signal resonance peak around 1.95 GHz) and modulated by a 2 GHz sinusoid (-30 to -10 dBm). The swept power range was adjusted to ensure minimal gain compression. The maximum gain compression was only about 1.5 dB, while the phase deviation was as high as 23°. Reflection noise around 2 GHz was also high. The corresponding fundamental and third-order intermodulation levels are shown in Fig.6. Large third-order intermod fluctuations occurred at low input power.

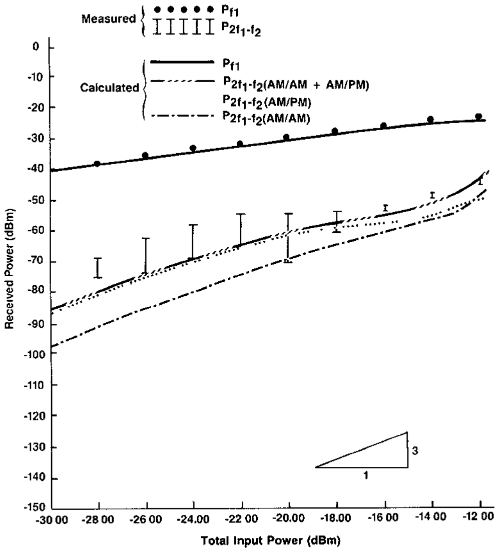

Figure 6 Dots and bars are the measured power levels of fundamental carrier (P_{f_1}) and third-order intermod ($P_{2f_1-f_2}$) under the same operating conditions as in Fig.5. Calculated P_{f_1} and $P_{2f_1-f_2}$ are shown as solid lines. Calculted $P_{2f_1-f_2}$ due only to the effect of AM/AM (broke line) or AM/PM (dashed line) are also shown. The third-order intermod power in general did not rise as the cube of the input power.

Analysis

An analysis similar to that used for GaAs FET amplifiers [5] or TWT amplifiers [6] was applied to determine the relative importance of AM/AM and AM/PM distortions. The two in-phase input tones with equal amplitude A , frequencies $\omega_o+\Delta\omega$ and $\omega_o+2\cdot\Delta\omega$ can be written as:

$$x(t) = A\cdot\cos(\,(\omega_o + \Delta\omega)\cdot t) + A\cos(\,(\omega_o + 2\cdot\Delta\omega)\,t) \\ = X(t)\cos(\,\omega_o\cdot t + \phi(t)) \tag{1}$$

and the received AC photocurrent can be expressed as:

$$i(t) = I(X)\cdot\cos(\,\omega_o t + \phi(t) + \theta(X)\,) \\ = G_p(X)\cdot X(t)\cdot\cos(\omega_o\, t+\phi(t)) - G_q(X)\cdot X(t)\cdot\sin(\omega_o\cdot t+\phi(t)) \tag{2}$$

where the first term in eq.(2) represents "in-phase" amplitude- nonlinearity, the second term represents "quadrature" amplitude- nonlinearity [7,8], and

$$X(t) = A\cdot\Big[\,\Big(\sum_{k=1}^{2}\cos(\,k\cdot\Delta\omega\cdot t\,)\Big)^2 + \Big(\sum_{k=1}^{2}\sin(\,k\,\Delta\omega\cdot t\,)\Big)^2\,\Big]^{1/2} \tag{3}$$

$$\phi(t) = \tan^{-1}\Big(\sum_{k=1}^{2}\sin(\,k\cdot\Delta\omega\cdot t\,)\,/\,\sum_{k=1}^{2}\cos(\,k\cdot\Delta\cdot t\,)\Big) \tag{4}$$

$$G_p(X) = \frac{I(X)}{X}\cdot\cos(\,\theta(X)\,) \tag{5}$$

$$G_q(X) = \frac{I(X)}{X}\cdot\sin(\,\theta(X)\,) \tag{6}$$

From eq.(2), it is clear that the measured AM/AM and AM/PM data can be related to I(X) and $\theta(X)$ respectively. By representing $G_p(X)$ and $G_q(X)$ with 4th degree polynomials of X^2, the coefficients of the expansions can be obtained by least square fitting the polynomial to the AM/AM and AM/PM measurements. The fundamental and third-order intermodulation as function of input power $\overline{X^2}$ can be calculated. Results are shown in Fig.3 and Fig.6. Match between measured and calculated data is fairly good. The contribution to third-order intermod by only AM/AM or only AM/PM can then be estimated by letting I(X) or $\theta(X)$ have zero variation. These results are shown in Fig.3 and Fig.6. For laser#1 biased at 1.3 times threshold current and with maximum modulating current swing slightly into the L-I curve knee region, AM/AM distortion contributes 10 to 15 dB more to third-order intermod than AM/PM. For laser#2 biased at 1.7 times threshold current and modulating frequency in the vicinity of resonance , the contribution to third-order intermod is dominated by AM/PM by 10 dB for small signals but when the driving signal becomes large AM/AM becomes predominant.

High reflection noise around the resonance peak is responsible for the wide AM/PM variations in Fig.4 and Fig.5. If the reflection noise is minimized, phase deviation can be significantly decreased. Therefore, third-order intermod for microwave modulation near resonance is dependent on the level of reflection noise. For microwave driving signals above about -10 dBm and near resonance, the sensitivity of AM/AM to reflection noise also becomes significant.

References

[1] G. L. Heiter,"Charaterization of Nonlinearities in Microwave Devices and Systems", IEEE Trans. on MTT, Vol. 21, pp.797-805, 1973.

[2] Bell Lab.,Transmission Systems for Communications, Chp.17, 5th ed.,1982.

[3] R. Soares, et al, Ed.,Applications of GaAs MESFETs, Chp.5, 1983.

[4] J. Abeles, et al,"Third-Order Nonlinearity of GaAs MESFET's", IEEE MTT-S Digest, pp.224-226, 1984.

[5] Y. Takayama and K. Honjo, "Nonlinearity and Intermodulation Distortion in Microwave Power GaAs FET Amplifiers", NEC J. Res. and Develp., No. 55, pp.29-36, 1979.

[6] J.J. Spilker, Jr., Digital Communications by Satellite, Prentice-Hall Inc., Chp.9, 1977.

[7] A.R. Kaye, D.A. George, and M.J. Eric, "Analysis and Compensation of Bandpass Nonlinearities for Communications", IEEE Trans. on Communications, pp.965-972, 1972.

[8] J. Minkoff,"The Role of AM/PM Conversion in Memoryless Non-linear Systems", IEEE International Microwave Symposium, Tech. Digest, paper 15.2, 1983.

[9] K.Y. Lau and A. Yariv,"Ultra-High Speed Semiconductor Lasers", IEEE J. Quant. Elect., Vol. QE-21, pp.121-137, 1985.