FLAT MICROWAVE RESPONSES OF DIRECTLY MODULATED LASER DIODES

M.C.R. Carvalho and A.A. de Salles

CETUC, PUC/RJ, Marquês de São Vicente 225, Gávea, CEP 22453
Rio de Janeiro, Brazil

1. ABSTRACT

Theoretical and experimental results of the frequency response of GaAlAs stripe-geometry laser diodes directly modulated in the microwave range are presented in this paper. Two methods of improving the frequency response flatness are described, the first using a passive microstrip circuit and the second using a FET driving amplifier. Experimental results for both techniques are presented and discussed.

2. INTRODUCTION

There are several applications using microwave analog or high speed digital modulation of injection laser diodes. These include antenna remoting, radar systems and connection between high speed computers. However,theoretical analysis shows that the intrinsic modulation response of a laser diode behaves like a low pass network, with a resonance (due to laser "relaxation oscillations") peak followed by an attenuated response [1]. The resonance peak results from the interaction of the photons with the injected carriers and is a function of the laser diode geometry and its active region material, as well as its DC bias current. For sinusoidal modulation, the effect of that resonance is to increase modulation efficiency, so that for frequencies in the vicinity of it, greater optical power modulation can be achieved for a given value of bias current modulation. However, the noise performance is significantly degraded in the vicinity of the resonance frequency [2,3]. For pulse modulation, the effect of the resonance is to produce distortion of short pulses and ringing on longer pulses [4]. This can seriously degrade the performance of a digital system by increasing the bit error rate. By increasing the laser DC bias current the resonance frequency is shifted to higher values, but the resonance peak is enhanced (eventually it reduces again) [5] and also the laser diode junction temperature is increased, reducing the laser diode lifetime. There is also likely to be failure due to optical damage to the emitting facets [3,4,5]. Therefore, for large bandwidth directly modulation, it is desirable to minimise the resonance effects, improving the laser diode frequency response flatness. This can be achieved by proper design of the laser diode input microwave matching circuit, as will be shown in this work.

In this paper an exact small signal equivalent circuit model for the intrinsic laser diode directly modulated in the microwave range is presented and then the laser microwave intrinsic frequency response (0.5 to 3GHz) is accurately predicted and measured. Also, using a computer optimization program, a passive and an active (FET driving amplifier) laser diode input circuit are designed to improve the frequency response flatness over the desired bandwidth. Finally, experimental results of the improved frequency response are presented and discussed.

The laser diodes used were GaAlAs/GaAs ($\lambda \sim$ 0,83 μm) double-heterostructure stripe-geometry Zn diffused, stripe width $\sim$ 18 μm. Typical threshold currents of these lasers were closed to 95mA, and the emitted optical power was about 2 mW and 4mW with bias current of 102mA and 108mA, respectively. The photodetector used was a silicon avalanche photodiode (APD) (type BPW 28 from Telefunken) also mounted in a microstrip circuit for wideband operation. The frequency response was measured using a computer controlled microwave network analyser (HP type 8410C).

3. PREDICTED AND MEASURED INTRINSIC FREQUENCY RESPONSES

The small signal laser diode equivalent circuit is obtained from the linearization of the rate equations relating the injection current, the number of carriers and the number of photons in the active region of the injection laser operating in single mode [4]. When the small signal equivalent circuit is obtained, the intrinsic frequency response can be predicted. That is compared with the measured frequency response (Fig. 1). Here,the frequency responses are normalized to the low frequency response, and the laser bias current is 10% above threshold. The resonance frequency is around 1.5 GHz. The decay of the measured frequency response for frequencies below resonance is attributed to substrate resistance and package parasitics [6,7]. The variation of the frequency response is typically of the order of 10dB in the bandwidth interest (from 0.5 to 2GHz).

4. IMPROVED FREQUENCY RESPONSES

The aim of the input compensation network is to improve, as much as possible,the laser diode frequency response flatness, over the bandwidth of interest. Therefore, over that bandwidth,the input

0149-645X/86/0000-0523$01.00 1986 IEEE MTT-S Digest

compensation network frequency response must be the reverse of that measured for the laser diode itself. This can be achieved using suitably designed passive[8] or active networks[9].

A band elimination filter centered at the laser resonant frequency and connected to the modulation input of the laser will reduce the modulation current at that frequency. Then the laser resonant peak will be minimized. In other words, a light response with the effects of the relaxation oscillation significantly reduced is obtained. Several kinds of passive circuits can be thought of, such as a series resonant circuit connected in parallel with the laser diode or a parallel resonant circuit connected in series with the laser diode. Because it is easier to implement in microstrip, a quarter-wave long parallel open stub was chosen. A 12 ohms damping chip resistance connects the stub to the 50 ohm microstrip laser input line. The value of the chip resistance was calculated in order to get a similar Q for the open stub as that measured for the laser resonance. The structure is represented schematically in Fig. 2, and in Fig. 3 its equivalent circuit is shown.

In Fig.4, a comparison of the measured normalized frequency responses of the laser diode with and without the suppressor circuit is shown.

Again, the laser bias current is 10% above threshold and the resonance frequency is around 1.5 GHz. It can be seen that a reduction of around 6 dB in the resonance peak is achieved using that suppressor circuit. Also, overshoot effects (under fast pulse modulation) are significantly reduced.

The active compensation network used a FET driving amplifier. In that, the FET input and output matching circuits are calculated to give a reduced gain in the vicinity of the laser resonance peak and the gain is increasing (up to a given frequency) for frequencies above it. Therefore, the response in the vicinity of laser resonance is reduced and the 3dB modulation bandwidth is extended. The reduction of the resonance peak and the enlargement that can be achieved in the modulation bandwidth depend on the behavior of the FET S parameters in the frequency range of interest, as related to the intrinsic laser frequency response.

The FET used in the driving amplifier was a GaAs MESFET from Dexcel (type DXL A-P70). Its S parameters have been measured from 0.5 to 8 GHz and using a computer optimization program (least squares method) its input and output matching circuits were designed to give the desired frequency response in one octave bandwidth centered at 1.5 GHz. In Fig. 5, a comparison of the laser diode normalized frequency response with and without the FET driving amplifier is shown.

It is seen that an extension of the 3 dB modulation bandwidth up to around 2 GHz and an improvement of around 7 dB in the frequency response flatness are achieved. These results could also be improved by using FETs with more convenient S parameters, which is presently being carried out as a continuation of this work. Depending on the application, the active or the passive network can be preferred.

5. CONCLUSIONS

The major results of this work were: 1) the exact modelling of the laser diode equivalent circuit; 2) the prediction and measurement of the laser diode frequency response in the microwave range; 3) the design and measurement of an active and a passive microstrip circuits to improve the laser diode frequency response flatness. These results may be useful to improve the performance of GHz/Gbit optical transmission systems.

In a future paper, the effects of the compensation circuits in the pulse responses will be shown.

6. ACKNOWLEDGMENTS

This work was supported by TELEBRÁS (Telecomunicações Brasileiras S.A.) under contract PUC-TELEBRÁS nº 28/83. The authors are grateful to Prof. M.M. Mosso for mounting the laser diodes on the microstrip circuits, to Eng. A. Brandão for the assistance in the measurements, to Engs. A.C. Bordeaux Rego and J. Salomão for supplying the laser diodes, and to Dr. A.J. Seeds for a critical appraisal of the manuscript.

7. REFERENCES

(1) Ikegami, T. and Suematsu, Y., "Direct Modulation of Semiconductor Junction Laser",Elect. and Comm. in Japan, vol.51-B, nº 2, 1968, pp. 51-58.

(2) Yamamoto, Y., "AM and FM Quantum Noise in Semiconductor Lasers",IEEE Journal of Quantum Electronics, vol. Q.E. -19, nº 1, January 1983, pp. 34-58.

(3) Casey, H.C. Jr. and Panish, M.B. "Heterostructure Lasers", Part. B: Materials and Operating Characteristics, Academic Press, 1978, Chapter 7, pp. 260-263.

(4) Kressel, H. and Buttler, J.K., "Semiconductor Lasers and Heterojunction LEDs", Academic Press, 1977, Chapter 17, p. 566.

(5) Thompson, G.H.B., "Physics of Semiconductor Laser Devices", John Wiley & Sons,1980,Chapter 7, p. 402.

(6) Tucker, R.S. and Pope, D.J., "Microwave Circuit Models of Semiconductor Injection Lasers", IEEE Trans. on MTT, vol. 31, nº 3, March 1983, pp. 289-294.

(7) Tucker, R.S., "High-Speed Modulation of Semiconductor Lasers", IEEE Journal of Lightwave Technology, vol. LT-3, nº 6,December 1985, pp. 1180-1192.

(8) Suematsu, Y. and Hong, T-H.,"Suppression of Relaxation Oscillation in Light Output of Injection Lasers by Electrical Resonance Circuit", IEEE Journal of Quantum Electronics, Q.E.-13, 1977, pp. 756-762.

(9) Angelov, I. et al., "Investigation of Microwave Properties of GaAℓAs Injection Laser", Proc. 13th European Microwave Conference, Nürenberg, Sept. 1983, pp. 494-497.

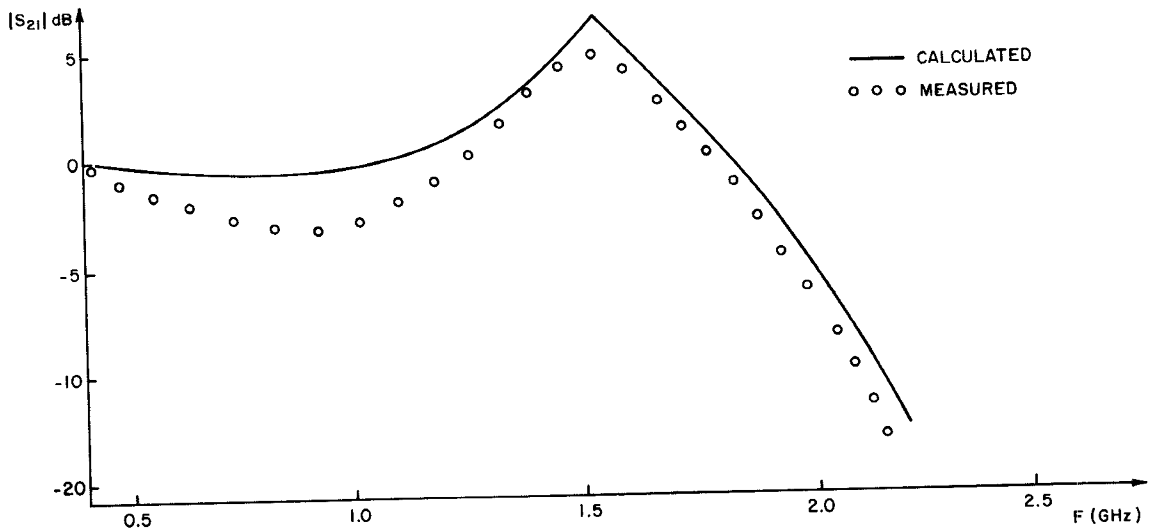

Fig. 1 - Predicted and measured normalized frequency responses of the laser diode.

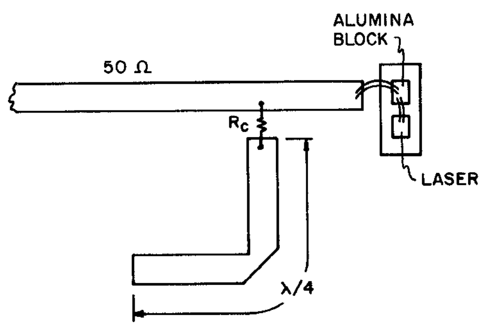

Fig.2 - Quarter wave open stub at the input of laser diode.

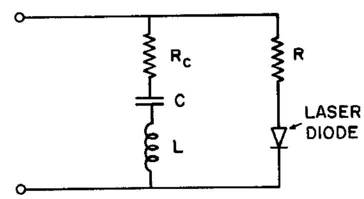

Fig.3 - Equivalent circuit for the structure of Fig. 2.

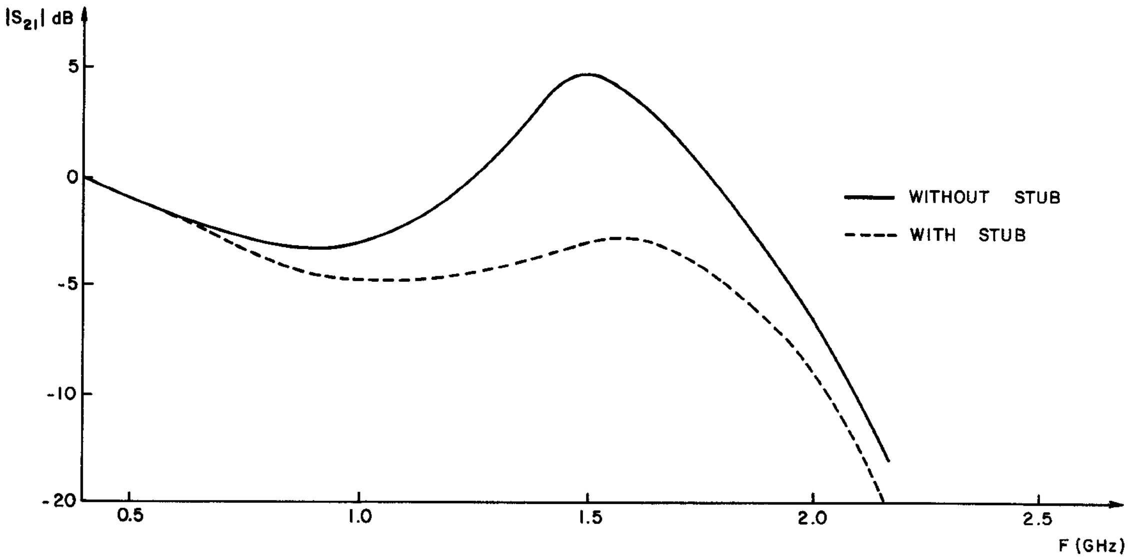

Fig.4 - Measured normalized frequency responses of the laser diode with and without oscillation suppressor circuit.

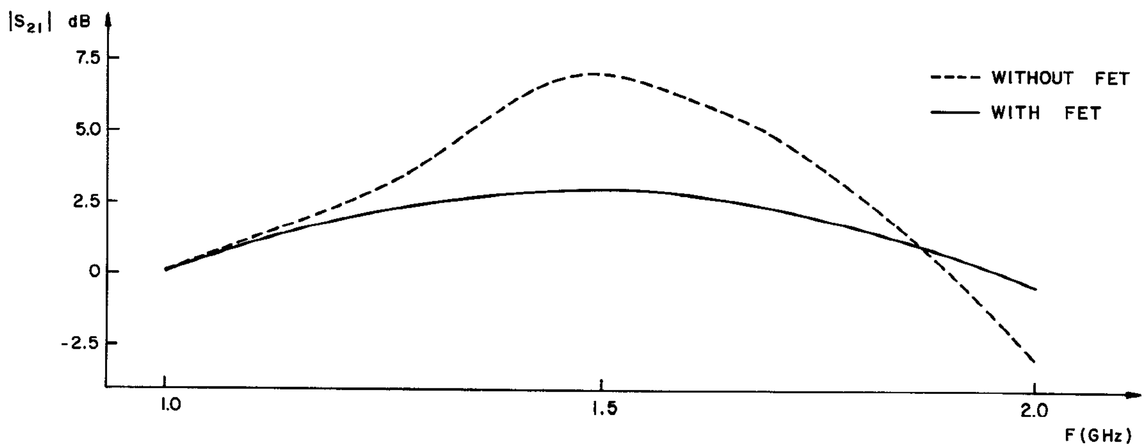

Fig.5 - Measured normalized frequency responses with and without the FET driving amplifier.