Detection and Mixing of Two Modulated Optical Signals Using only a Single GaAs FET (Experimental Study)

L. A. Pérez-Pérez[1], J. A. Reynoso-Hernández[1], J. R. Loo-Yau[1], G. Soberanes-Flores[1], H. Ascencio-Ramírez[1] and R. Rangel-Rojo[2]

Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE) División de Física Aplicada, Km. 107 Carretera Tijuana-Ensenada, 22860 Ensenada, B.C. México

[1] Departamento de Electrónica y Telecomunicaciones [2] Departamento de Óptica

Abstract.- GaAs FET's are widely used in system such LNA, PA, mixers, frequency multipliers, oscillators and attenuators. Recent works have shown the usefulness of these transistors in the optoelectronics field, as photodetectors or optoelectric mixers. In this paper an experimental study explores the idea of unifying the detection and mixing of two optical modulated signals at different wavelengths, using a single GaAs FET. The FET is biased at fixed V_{GS} and V_{DS} and loaded to 50Ω, while two optical modulated signals of different wavelength and frequencies are illuminating the gate of the FET. The results show that the FET can detect both signals and by means of the inherent nonlinearity in the channel of the FET, the sum and difference of both frequencies appear (up and down conversion). Moreover, this type of architecture demonstrates low distortion in contrast to its counterpart (electric and optoelectric mixers) and also, to obtain the same power level for the up and down conversion frequencies, the power level required for the RF and LO signals are much lower than the case of electric and optoelectric mixers. To our knowledge this is the first time that a single FET is used for detecting and mixing two optical modulated signals at the same time.

I.- INTRODUCTION

In the last decade, certain research groups have studied the effects of direct optical illumination on GaAs FET's [1-3] with the intention of using them for optic communications. Typical applications reported using this technique are: the synchronization of oscillators [7], phase detection [8] and optoelectronic mixing [2-3].

Nevertheless, before developing the system previously mentioned it is necessary to understand the effects that the light produces in the FET. Basically the photoresponse in GaAs FET's depends on the properties of the semiconductor. Furthermore, the mechanisms that explain the photoresponse in GaAs FET have been reported and demonstrated in the past [4-6]. The two basic effects related with the photoresponse are the photovoltaic (internal and external) and photoconductive.

The photoconductive effect is the increment of the conductivity due to the photogenerated carriers. On the other hand, when the photon energy of the light impinging on the semiconductor is larger than the material bandgap, the transistor absorbs a photon, and therefore the channel is modulated. This represents an increment in the drain current, and this effect is called internal photovoltaic effect. The external photovoltaic effect is related with a photovoltage that is induced by the illumination on the gate when an external resistor is connected in the gate circuit. This implies that the transistor should be constructed such that the incident light reaches the active region with minimum attenuation. However, this fact is not very common because most of the GaAs FET's are optimized for high frequency amplification.

In recent years several research groups have shown that a microwave signal can be mixed with a modulated optical signal using GaAs FET's [2], [3], [4]. Another experiment reported deals with a self-oscillating optoelectronic up converter using HBT [1]. In this approach, the HBT is configured as an oscillator, and a modulated optical signal illuminates the HBT producing the mixed signal at the output.

However, the mixing of two modulated optical signals of different frequencies and wavelengths has not been shown yet. Therefore, the motivation in this work is to demonstrate that a single GaAs FET's can be used for detecting and mixing two different modulated optical signals at the same time without the necessity of an external electric signal (oscillator). This architecture shows a much higher IM3 suppression than the electric and optoelectric mixers; implying that an external filter with narrow band could be replaced with a broadband filter. In addition, to obtain the same power level for the up and down conversion frequencies, the power levels of the detected signals (RF and LO) are much lower than the case of electric and optoelectric mixers.

II.- SETUP CONFIGURATION AND MEASUREMENTS

In this section, a complete description of the workbench used in this work is described. For our experiment a MESFET and PHEMT GaAs FET were used. To observe their behavior under illumination, the I-V characteristics were measured for both FET's using a Dynamic I-V Analyzer (DIVA) along with a monochromatic laser. A description of the setup configuration is presented in figure 1. Figure 2 shows the photoresponse of the MESFET, a similar response was obtained for the PHEMT (NE24200). In the I-V pulsed measurements, the width of the pulse used was 0.5μs, and a pulse separation of 1 ms. These conditions ensured that we could avoid traps effects.

Due to the bandgap of the GaAs (1.42eV), lasers with wavelength less than 873nm can be used to generate free carriers in the transistor. Therefore, for this study two laser, one at 830nm and the other at 850nm were used. Once the wavelength of the lasers was defined, a second measurement was performed. The objective of this measurement was to determine the frequency band where the maximum photodetection is produced. Hence, a frequency sweep from 50MHz up to 1GHz was performed. The result shows that the maximum photodetection occurs at low frequency as shown in figure 3. Higher frequencies were not studied due to the limitation of our modulator (THORLABS TCLDM9), which works up to 1GHz. Therefore, the RF and the LO signals were chosen to be 100MHz, and 500MHz respectively.

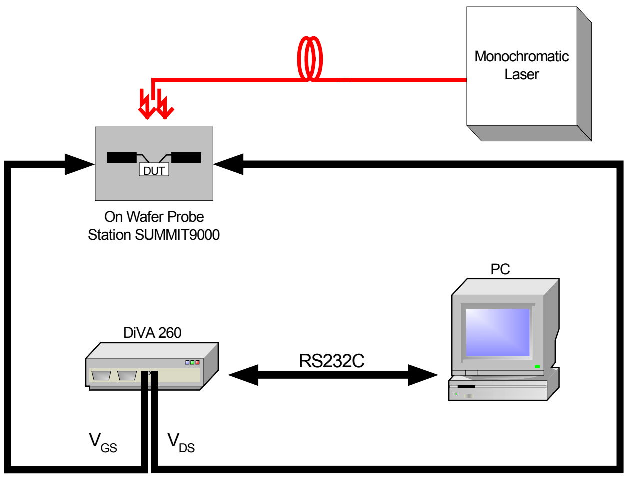


Figure 1. Experimental setup for I-V measurement using a dynamic I-V analyzer.

Once the conditions of operation have been determined, three configurations for mixing the RF and LO signals were investigated. The first one is a classical configuration in which the RF and LO are combined and injected directly to the gate of the FET. So, this configuration will be further referred to as the electric case. A description of the setup configuration for this case is presented in figure 4.

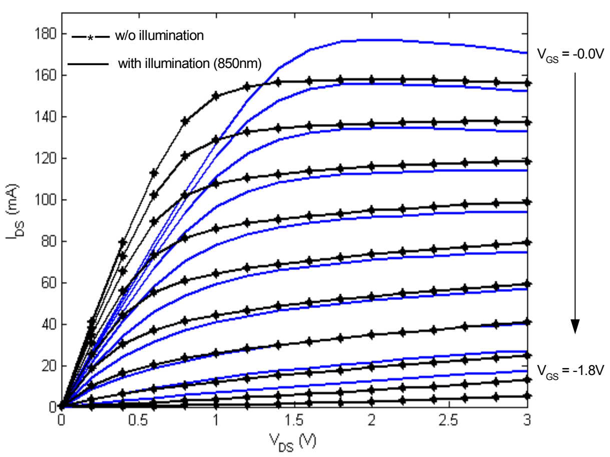


Figure 2. Pulse I-V characteristic of the MESFET. (Solid line) without illumination, (+) with illumination

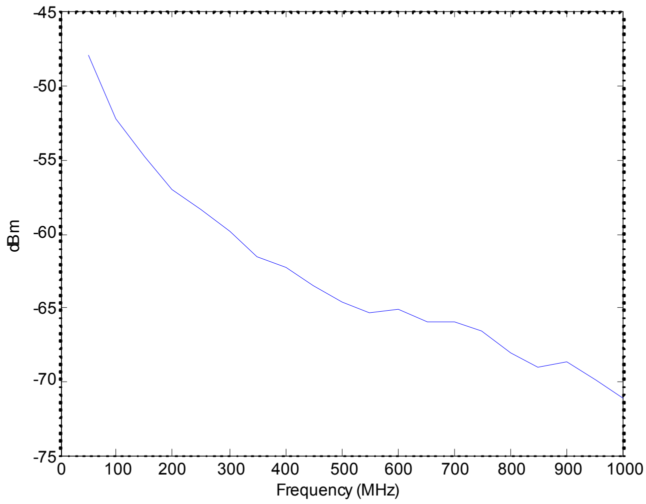


Figure 3. Frequency dependence of the photoresponse for the MESFET at 850nm (0.62mW).

In the second configuration the LO signal is applied to the gate of the FET while the RF signal is an optical modulated signal that illuminates the gate of the FET, as shown in figure 5. It is worth to comment that this configuration is extensively used in optoelectronic mixers [2-3], hence, this configuration will be referred to as the optomixer case.

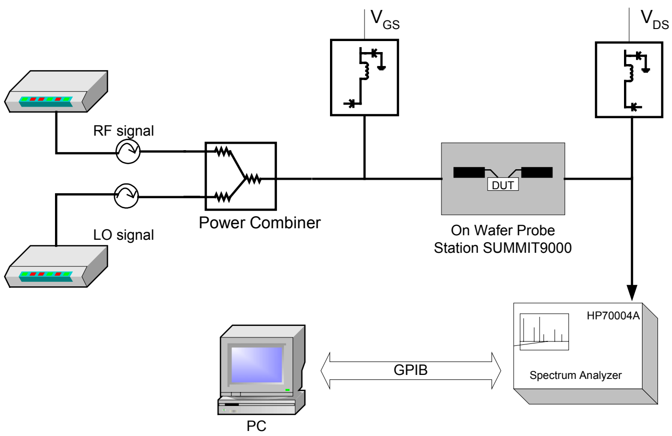


Figure 4. Workbench for the electrical case.

Finally the last configuration does not utilize any electrical signal, this means that both the RF and LO are optical modulated signals. To the best of our knowledge this type of configuration has not been reported yet. This configuration will be called the optic-optic case. The configuration of the workbench is presented in figure 6.

The results for this entire configuration are presented in the next section. It will be clear that the last configuration presents a better performance in IM3 than the other two configurations as well as other advantages.

III.- EXPERIMENTAL RESULTS

In this section the spectrum at the output of the MESFET is presented in order to demonstrate the differences between each type of mixer (electrical case, optomixer case, and the optic-optic case).

The results for the electrical mixer are shown in figure 7. The RF (100MHz) and LO (500MHz) signals can be clearly discerned, as well as the IF (400MHz and 600MHz) and other IMD products.

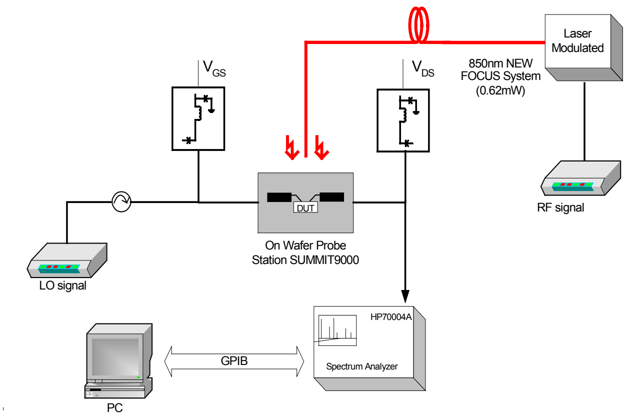
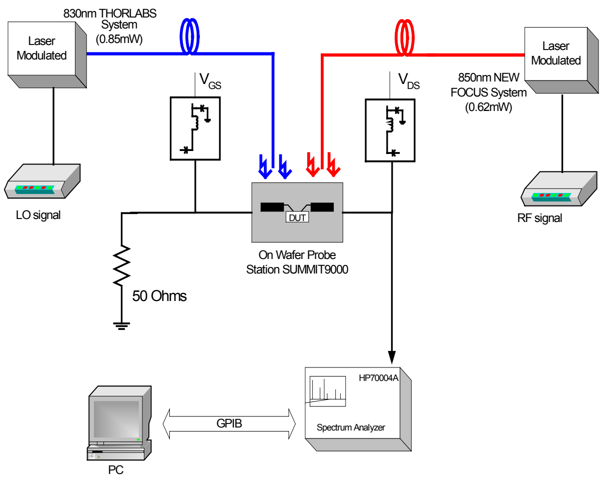


Figure 5. Workbench for the optomixer case.

For this case the power of the LO is greater than the RF power. These results are for the MESFET at V_{GS}=-0.35V, and V_{DS} = 1.0V, while the power levels for the two IF were -59.33dBm and –60.7dBm respectively.



igure 6. Workbench for the optical-optical case.

For the optomixer case, figure 8 shows the results for the same MESFET and same bias conditions. It is worth mentioning that the laser wavelength used in this case was 830nm and the photodetected level was –33.3dBm, which correspond to the RF signal. At this same bias point the optomixer shows more distortion at the output than the electrical case. Furthermore, the IF power levels are similar to the above case (-55.9dBm and –56.9 dBm). A better performance could be reached if the bias point is changed.

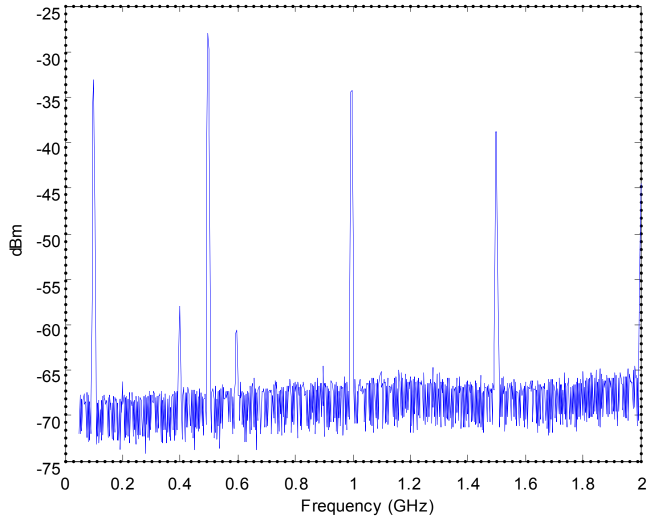


Figure 7. Output spectrum for the electrical case.

The output spectrum of the optic-optic mixer case is shown in figure 9. In this case the LO and RF are two optical signals, the LO signal was modulated with the 830nm laser, while the RF signal was the 850nm laser. The figure clearly shows that the performance is much better than the other cases.

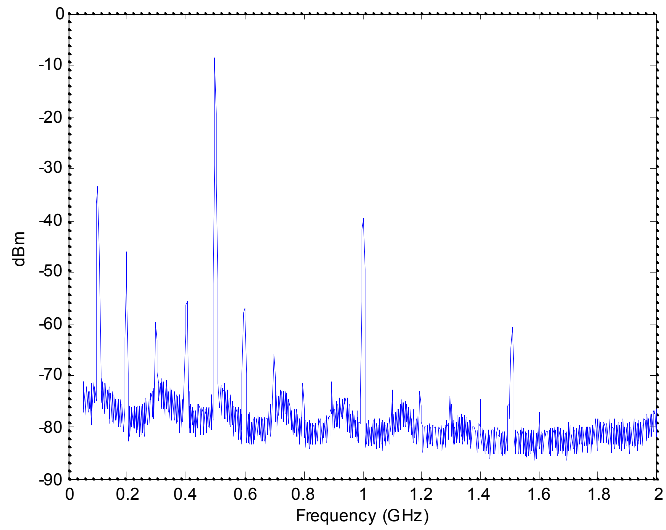


Figure 8. Output spectrum of the optomixer case.

The main advantage that can be seen in this case is the low power levels required for the LO and RF signals. These powers are lower than in the other two cases (-27.98dBm and –33.04dBm), however, the power levels of the IF obtained are –57.93dBm and –60.62dBm. The IF power levels are similar to the others two cases, and in addition, there is considerably less distortion.

For the optomixer, figure 8 reveals the presence of higher harmonics of the LO signal with considerable power levels. This fact was expected due to a P_{in}-P_{out} test. The experiment reveals a significant increment of the output power using a modulated laser at 830nm, and at the same frequency of the input.

Similar behavior was observed in the PHEMT, a summary of the experimental results obtained with the PHEMT is presented in Table I.

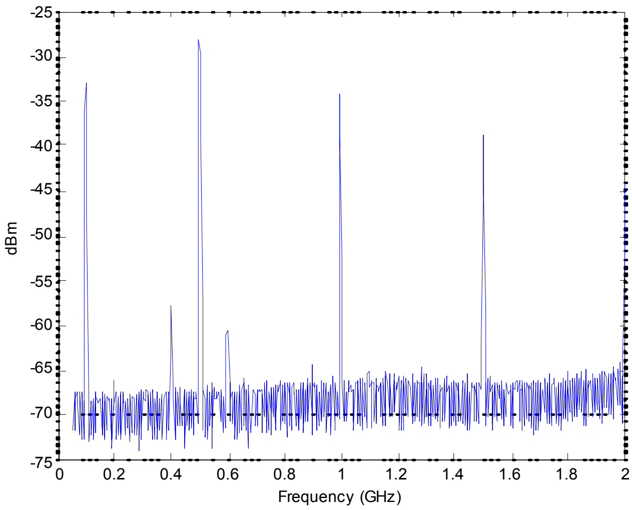


Figure 9. Output spectrum for the optical-optical case.

IV. CONCLUSION

In this work the potential use of MESFET and PHEMT for detection and mixing of two optical modulated signals at the same time was investigated. It was shown for the first time that commercially available MESFET and PHEMT devices are capable to detect and mix two optical signals modulated at two different frequencies and wavelengths. This topology has demonstrated a better performance (high IM3 suppression), however, harmonics of the LO signal are observed at the output of the mixer. A comparison between an electrical mixer, an optoelectronic mixer, and a proposed optic-optic mixer was made. The results show that in order to obtain the same power level of IF, the FET requires less power for optic-optic mixer.

V. REFERENCES

[1] H. Swada, N. Imai, "An Experimental Study on a Self-Oscillating Optoelectronic Up-Converter that Uses a Heterojunction Bipolar Transistor," IEEE Trans. on Microwave and Tech., Vol. 47, No 8, pp. 1515-1521, Aug 1999.

[2] Chang-Soon Cho, Hyo-Soon Kang, Dae-Hyun Kim, Kwang-Seok Seo, and Woo-Young Choi, "Characteristics of InP HEMT Harmonic Optoelectronic Mixers and Their Application to 60GHz Radio-on-Fiber Systems," in IEEE MTT-S Int. Microwave Symp. Dig., pp. 401-404, Texas, 2004.

[3] Chang-Soon Choi, Woo-Young Choi, Dae-Hyun Kim and Kwang-Seok Seo, "A Millimeter-wave Harmonic Optoelectronic Mixer based on InAlAs/InGaAs Metamorphic HEMT," in IEEE MTT-S Int. Microwave Symp. Dig., pp. 1383-1386, Philadelphia, 2003.

[4] A. A. de Salles, "Optical Control of GaAs MESFET's," IEEE Trans. on Microwave Theory and Tech., Vol. MTT-31, pp. 40-45, October 1983.

[5] A.Paolella, P. R. Herczfeld, A. Madjar, and T. Higgins, "Optical Response of the GaAs MESFET at Microwave Frequencies and Application," IEEE MTT-S Int. Symp. Digest, pp. 487-490, 1991

[6] Asher Madjar, Peter R. Herczfeld and Arthur Paolella, "Analytical Model for Optically Generated Currents in GaAs MESFETs," IEEE Trans on Microwave and Tech., Vol. 40, No. 8. August 1992.

[7] R. D. Esman, G. Lew and J. F. Weller, "Optical Phase Control of and Optically Injection Locked FET Microwave Oscillator," IEEE Trans. on Microwave Theory and Tech., Vol. 37, No 10, pp. 1512-1518, 1989.

[8] Tibor Berceli, "A MMIC Based New Ligthwave-Microwave Phase Detecto," in 21st Euro Microwave Conf. Proc., Cannes, France, Sept 1994.

ACKNOWLEDGMENT

The authors would like to thank Centellax Inc, for providing the probes and PHEMTs. This work was supported by a joint funding of CICESE and CONACYT project No.39835-Y, Mexico.

PHEMT NE24200	Power Level of the RF Signal (100MHz)	Power Level of the LO Signal (500MHz)	Power Level of the Down Conversion	Power Level of the Up Conversion
Electrical Case	-14.52 dBm	-4.42 dBm	-53.62 dBm	-54.42 dBm
Optomixer Case (830nm)	-25.78 dBm	-9.92 dBm	-54.52 dBm	-56.22 dBm
Optomixer Case (850nm)	-29.04 dBm	-9.66 dBm	-56.95 dBm	-59.2 dBm
Optic-Optic Case	-34.08 dBm	-30.6 dBm	-55.78 dBm	-56.08 dBm

Table I. Results of the PHEMT