CW LASER Control of MMICs

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Abstract — The results of our research on the electro-optical control of MMICs are shown in this paper. Two different devices have been investigated: a GaAs chip monolithic amplifier at S band, and an AlGaAs chip MMIC voltage controlled oscillator at Ku. The possibilities of optical control of the amplifier are evidenced as follows: if the amplifier operates with the same biasing, the gain can be optically controlled from a condition of almost isolation, , up to an active condition, which gives a range of optical control of about 15 dB and provides an improvement of the input and output matching in a range of 12dB and 6dB, respectively. The possibilities of optical control of the VCO by illumination of the PHEMT transistor are demonstrated through measurements of the oscillation output power and frequency. An optical control range of 8dB of oscillation output power and up to 400MHz of oscillation frequency has been obtained. This optical control suggests an interesting control of gain and matching for other microwave FET based active devices.

1. Introduction

An increasing interest in the use of microwave and optical systems, together with the possibility of integrate on a single chip microwave and optical components; have stimulated R&D activities in the area of hybrid optical-microwave systems. Phased-array antennas, receiver front-end and distribution systems or innovative sensors, among other potential applications, can benefit from those techniques.

Since the early 1980s, a relevant part of published work has been concentrated on merging lightwave and microwave technologies, demonstrating the feasibility of optical control of microwave signals in a number of different circuit functions [1]-[2]. GaAs MESFET and HEMT devices are the more commonly active devices used in microwave circuit design, and many researchers, including our group, have developed accurate MESFET and HEMT models which include optical effects [3]-[6].

A summary of our works on electro-optical control for two different microwave MMICs devices: an amplifier and a VCO, is presented in this work.

When a semiconductor is illuminated by a laser at a fixed wavelength, the device exhibits both photovoltaic and photoconductive effects [3]-[4]. This means that the static DC curves and pulsed I-V curves, as well as the small signal equivalent circuit parameters, change when optical energy is absorbed by the device. A detailed description of the measurement setup is given in [3].

2. Measurement Set-Up

The optical source used in the present work is a continuous wave laser diode from SDL Optics Inc. Model: 5301-G1 pigtailed to a single-mode optical fiber (5/125). This device uses the first window (λ=830 nm and maximum optical power PL=10 mW), furthermore, the fiber is supported by an in-house fiber holder in order to get a correct alignment of the laser spot and the semiconductor surface to be illuminated.

From the optical fiber parameters, conditions are obtained for the far field Gaussian profile [3]. The Gaussian beam diameter at the fiber end is W_o=3.1 μm and the diffraction angle is fixed to φ=0.085 rad. The optical energy distribution over the FET surface

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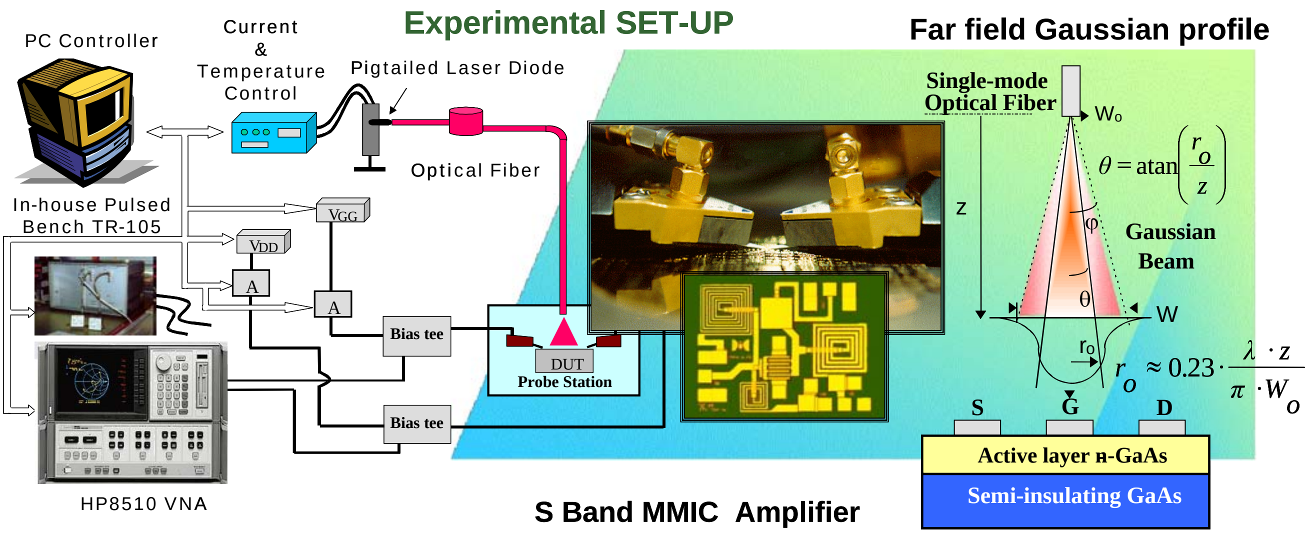

Fig. 1. Optical-microwave measurements set-up.

is not uniform, but we can take like effective region that where the 90% of the energy density is concentrated (Gaussiam beam), as is shown in Fig.1.

2.1 The MMIC Amplifier

The MMIC amplifier used in this work has been manufactured using GaAs F20 technology from the GEC Marconi foundry, with a 0.5µm gate width. This single stage amplifier designed, consists of a GaAs MESFET transistor with 6 fingers, and 175µm of gate periphery. The input network has a π configuration, while the output consists only of a hairspring inductor and a MIM capacitor that allows a good output match. Fig. 1 shows the microphotograph of the GaAs MMIC amplifier used in this work, and its electrical diagram is shown in Fig. 2.

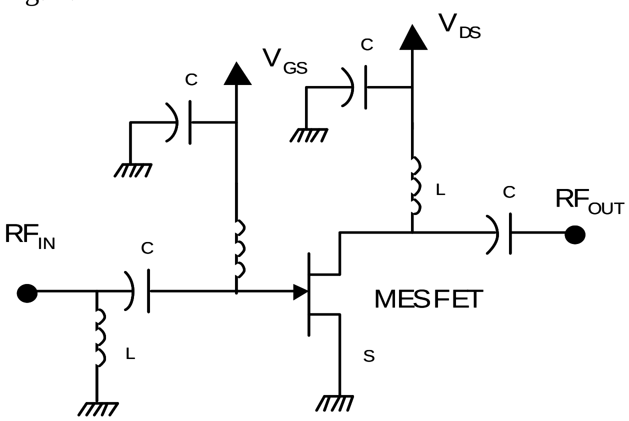

Fig. 2. Electrical scheme of the GaAs MESFET amplifier.

Furthermore, it can be appreciated in the microphotograph the necessary contact pads to place the coplanar test probes (R_{FIN} and R_{FOUT}), as well as DC biasing. This allows the device characterization directly with a coplanar probe station Cascade SUMMIT 9000 and a VNA model HP8510C from Agilent Technologies.

The final size of the MMIC amplifier including the pads is only 1400 by 1050 µm.

2.2 The MMIC Voltage Controlled Oscillator

The VCO has been manufactured with the D02AH technology from OMMIC, and it is based on an AlGaAs pseudomorphic HEMT (P-HEMT) transistor with a 0.2µm gate width. The microphotograph, of the oscillator has been omitted here for simplicity, but its electrical diagram is shown in Fig 3. The voltage controlled oscillator designed here, consists of an AlGaAs PHEMT transistor with 6 fingers, and 50µm of gate periphery.

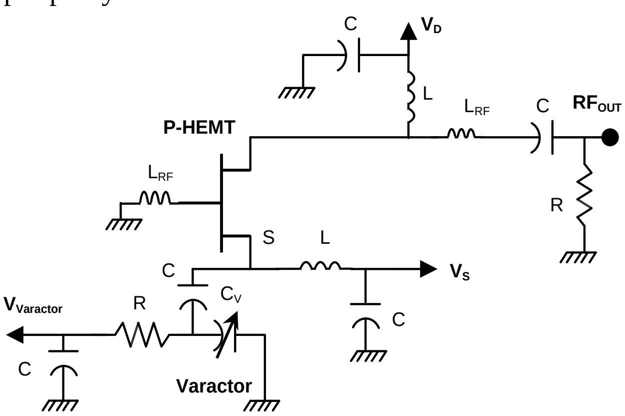

Fig. 3. Electrical scheme of the AlGaAs PHEMT VCO.

To get the appropriate frequency, the electrical control of the VCO has been implemented by the varying the bias of a varactor diode. This varicap has been designed using the Schottky junction of another P-HEMT transistor with 4 fingers and 30µm of gate periphery that uses the same technology, and is connected to the source terminal of the 6 finger device. This interconnection allows the oscillator to get a wide bandwidth (600 MHz) with a reasonable SSB phase-noise (-85 dBc/Hz at 100 KHz).

In order to avoid possible inductive mismatches that could affect the output frequency stability, due to the bonding process used in the bias wire, the gate biasing of the main transistor (6 finger device) has been made through a hairspring inductor [8]. This inductor, coupled to the output network, is used to modify the load circle of the transistor in order to improve the frequency tuning of the VCO. The final size of the VCO including the pads is 1200 by 750 microns.

3. Optical control of microwave devices

In order to establish the accurate FET optical operation, preliminary experiments on the DC and pulsed I-V curves, along with S-parameter measurements under different optical powers, were performed for the transistor alone, but not for the complete MMIC (amplifier and VCO) and those results were reported in previous communications by our group [5-7].

3.1. MMIC Amplifier at S Band

When the laser spot is properly positioned over the fingers of the transistor, and the DC bias point selected (Vgs=-1.2V, Vds=3V in our case), measurements of the amplifier scattering parameters in the band of interest (2-4 GHz) can be performed, as well as some of its main electrical characteristics. For example, input-output matching and small signal gain can be evaluated as a function of the incident optical power on the transistor.

The optical power range has been varied from 0 mW (darkness) up to 10 mW, and the variation of the scattering parameters for the amplifier studied here are shown in Fig 4, where an improvement in the small signal gain (S_{21}) and the input-output matching variations (S_{11} and S_{22}) can be observed.

A deep increment in the input and output matching can be observed in Fig. 4(a) and Fig. 4(b), 12dB and 5dB, respectively. The improvement in S_{22} is clear (more than 8dB at 2.4GHz), however for S_{11} only 3 dB of improvement has been reached at that frequency. At 2.9GHz the improvement can be of up to 11dB. Such improvement is produced because the amplifier has a mismatching design error in the input impedance at 2.4GHz. The amplifier under non-illumination conditions has better input match at 2.9 GHz than at 2.4 GHz, but under 10mW of optical power the matching is increased in the whole measurement bandwidth (2-4 GHz).

The improvement of almost 17dB from dark conditions (0mW) up to 10 mW of CW laser optical power applied in the S_{21} scattering parameter as responsible of the small signal gain, is shown in Fig. 4(c) when the amplifier is biased at Vgs=-1.2V, Vds=3V.

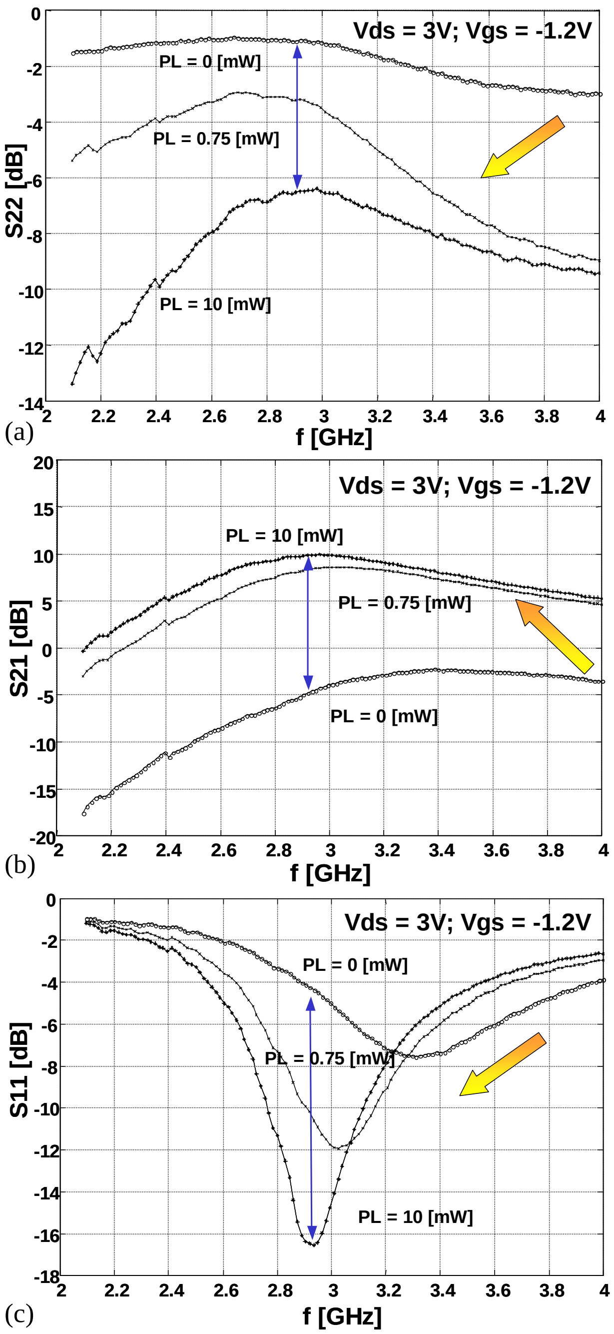

Fig. 4. Variation of the S-parameters magnitude for the MMIC amplifier under optical illumination. *(The arrow orientation indicates the increasing of the optical power from darkness PL= 0mW, PL=0.75mW and PL=10mW).* (a) S11 (b) S22 (c) S21.

Fig. 5 shows the variation of the scattering parameter S_{21} as a complex quantity (magnitude and phase) for the MMIC amplifier in the Smith Chart.

The frequency bandwidth of the measurements is 2-4 GHz and the DC bias point for the single stage MESFET amplifier is the same that has been used for Fig. 4 (Vgs=-1.2V, Vds=3V). The increase of small-signal gain is clear when laser illumination is applied to the microwave amplifier.

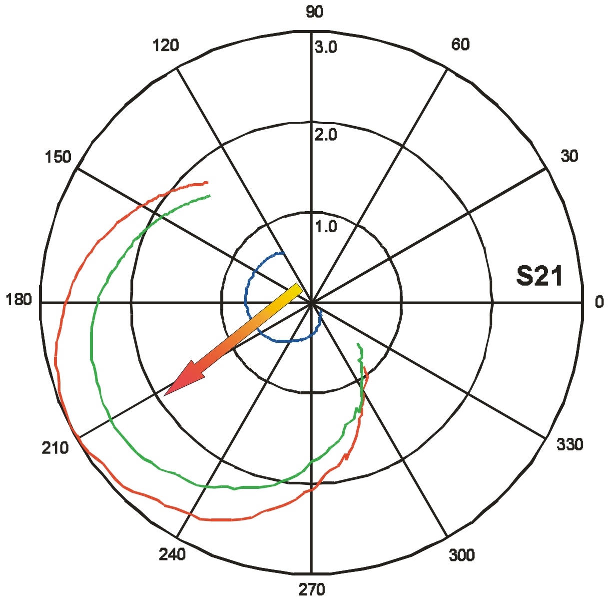

Fig. 5. Variation of the S_{21} parameter of the MMIC amplifier under optical illumination. Arrow indicates the increasing of the optical power from darkness PL 0mW, 5mW and 10mW.

3.2 Ku Band MMIC VCO

In this section the results obtained for the MMIC VCO at Ku band will be shown. When the laser illuminates the main transistor of the VCO, (not over the PHEMT used as a varactor), and the bias point is properly selected, output power and oscillation frequency can be evaluated as a function of the incident optical power on the transistor.

Figure 6 (a) shows the variation of VCO output power as a function of the optical power applied for two different varactor voltages, (0 and -0.6 V), keeping the drain voltage fixed at 1.8V in both traces.If the varactor voltage is fixed to 0V (Vvar=0V), the output power of the microwave VCO is independent of the optical illumination. As a consequence of this, the output power is independent of the circuit capacitance and this capacitance depends strongly on the optical power applied [5]. The optical tuning range for this microwave VCO, varies only 200MHz when increasing the varactor biasing (Vvar=0V and Vvar=-0.6V), as is shown in figure 6 (b).

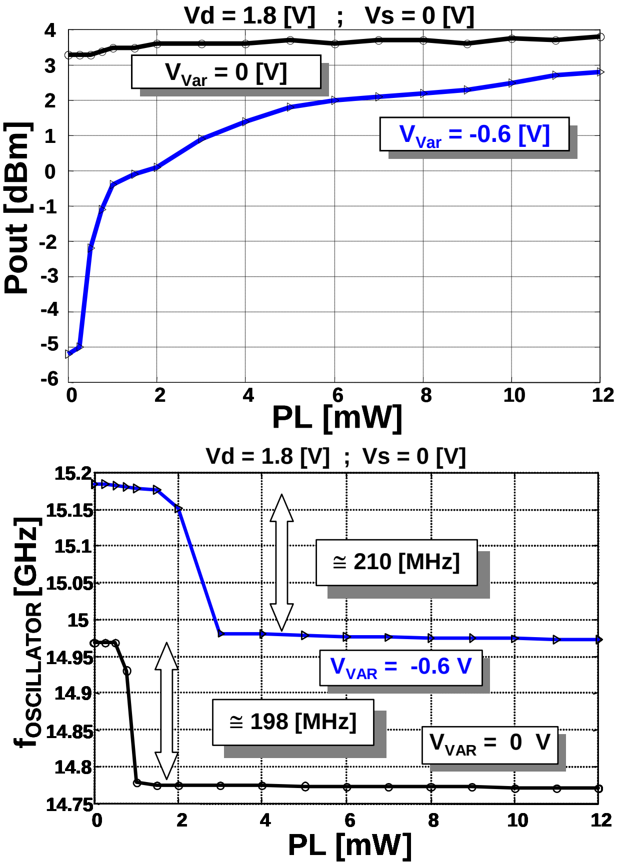

Fig. 6. (a) VCO RF Output power as a function of optical power (PL), for two different varactor bias 0 and -0.6V, when PHEMT is biased at Vds=1.8V.

(b) VCO oscillation frequency tuning as a function of optical power (PL), for two different applied varactor voltages (0 and -0.6V).

As a conclusion of these results, it can be establish that when the microwave FET transistor of a MMIC is biased near the pinch-off region, the effect of optical illumination is more significant than at other gate bias and a control of the output power is possible.

This is a very interesting property for low consumption transceivers, because the user can increase the RF output power using optical signals, while in stand-by conditions, the device does not consume DC energy since the amplifier is biased near pinch-off and the batteries increase their operative life. As it could be expected from theory, the effect of the optical illumination on the main PHEMT transistor of the VCO decreases the value of the oscillation frequency due to the increment of the gate to source capacitance of the microwave FET used in the circuit.

4. Conclusion

This work reports an exhaustive investigation of the control properties of a GaAs MMIC amplifier at S band and a AlGaAs MMIC VCO at Ku band under optical illumination has been performed. The main dependencies of its parameters, as well as the way of integrating their behavior into other classical controlling techniques for the drain and gate currents has also been shown.

As a conclusion of the work presented here, it can be established that the CW laser optical control gives the user another port to modify the characteristics of the microwave device, the small signal gain and input-output matching in the case of the MMIC amplifier and the oscillation frequency and output power for the VCO. In that sense the acronyms OVGA (Optical Variable Gain amplifier) and OVCO (Optical and Voltage Controlled Oscillator) must be used in the future to refer to this kind of devices.

The optical control procedure presented here is also valid for other types of microwave components and subsystems such as oscillators, mixers, up-converters, down-converters, modulators, etc. and this technique may improve the development of future generations of OMMICs.

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