OPTICAL TUNING IN GaAs MESFET OSCILLATORS

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ABSTRACT

Optical tuning in GaAs MESFET oscillators indicate that the tuning range is an order of magnitude greater in common-source and common-gate mode oscillators compared to common-drain mode circuits. Tuning ranges of 2 to 3% at C and X band have been demonstrated with an incandescent source illumination intensity of approximately $1mW/mm^2$. The optical tuning sensitivity is attributed to C_{gs} variations with light, resulting from an increase in the effective space charge density in the gate depletion layer (attributed to hole trapping). Analysis of the oscillator starting condition for the three oscillator circuits is in qualitative agreement with the measured frequency sensitivity, using C_{gs} variations with light measured at 1MHz.

Introduction

Recent studies indicate that the electrical characteristics of GaAs MESFETs have a good optical responsivity, being proposed for high speed optical detectors and optically-tuned oscillators.[1,2] To fully utilize this optical sensitivity, the mechanisms governing the optical-electrical response need to be well understood and controlled by device and/or circuit design.

In this paper the optical sensitivity of common-source (CS), common drain (CD) and common gate (CG) MESFET oscillators are compared using low power, commercial 1μm devices. Initially, two device mounting and circuit implementations are described, followed by the microwave oscillator results. Then the theoretical optical-frequency sensitivity of the three circuit configurations are obtained, from analysis of the oscillator starting condition and 1MHz capacitance measurements of C_{gs} variations with light. At the end summary and conclusions are presented.

Experimental Procedures

Two oscillator circuit configurations were implemented on 25 mil alumina microstrip. The first incorporated a chip-on-a-disc device mounting, bonding wires for gate circuit tuning and a circular metallic disc for output impedance matching, implemented on a single 1" by 0.7" microstrip circuit. Both CS and CD oscillators could be evaluated, the latter using the "reverse-channel method".[3]

The seond utilized a 0.2" by 0.45" planar microstrip device mounting, with separate tuning and output matching circuits of similar electrical design as before. By interchanging the connections between the device-mounted microstrip and these two passive circuits, either CS, CD or CG circuits could be achieved. This latter circuit is depicted in Figure 1, with the interconnections shown for the CG mode.

In the experiments several commercial 1μm low power MESFETs have been used with similar results. A 60 W incandescent light source, a quartz halogen lamp to simulate AM1 illumination and a He-Ne (6328Å) laser were used as optical sources. With an optical intensity selected to give the same change in drain current, similar oscillator changes were obtained with all optical sources. For convenience, optical results presented in this paper were taken with the incandescent light source, mostly with an estimated illumination intensity at the device surface of $1mW/mm^2$. The results taken as a function of light intensity were obtained by adjusting the distance between the optical source and device surface.

Microwave Oscillators Results

Experimental results on a variety of CS and CD oscillators using the chip-on-a-disc device mounting are shown in Tables 1 and 2. The differences in oscillator power, efficiency and frequency without illumination are mostly indicative of differences in device mounting and circuit Q's, as emphasis was placed on oscillator changes with light rather than optimizing oscillator performance without illumination. These results indicate that the oscillator frequency decreases with photoillumination, and the CS oscillator is an order of magnitude more sensitive to the photoillumination than the CD oscillator.

Typically the power output of the oscillator increases (0.5 to 2.0dB) at the nominal illumination inintensity, although the power eventually decreases at sufficiently high optical intensity, nominally 2 to 10 times the nominal illumination intensity. The specific RF power and frequency dependence is sensitive to actua tuning conditions, with results for the GAT 5-01 device at X band shown in Figure 2.

In order to compare the optical sensitivity in the CG mode as well, devices were mounted in the circuit of Figure 1, and tuned and matched with high Q elements. Data for an HFET-1000 device is shown in Table 3. Comparable power and conversion efficiency were obtained i three circuit modes, but the CS mode oscillated at X band with the CD and CG modes at C band. The same tuning circuit was used in all cases, while the output matching was optimized using a variable (both diameter and position) metallic disc.

Both the CS and CG modes had an order of magnitude more frequency sensitivity to light than the CD mode, with the CS mode somewhat more sensitive. These result are compatible with the previous data. However the oscillator power and frequency variations with light stabilized at intensities below half the nominal optical intensity and were relatively unchanged at the highest intensities used (8 times nominal intensity). This dif ference in characteristics with optical intensity is currently being investigated further.

Analysis of Optical Tuning

Based upon previous work on photoeffects in GaAs MESFETs,(1,4) we postulated that the optical tuning was principally a result of C_{gs} variations with light. Oscillation starting conditions were derived for CS, CD and CG configurations assuming that parallel feedback dominated, using first order device equivalent circuits such as shown in Figure 3. The tuning circuit (X_G in CS and CD modes) and output matching circuit (R_L and X_L) were varied in the circuit analysis to achieve self-starting, i.e. the voltage feedback to C_{gs} being in phase with an initially assumed voltage.

In order to utilize this circuit model to calculate oscillator frequency changes with light, the device equivalent circuit parameters without illumination, either the tuning circuit or output circuit parameters (the other can be calculated) and the C_{gs} variation with light (and any other device parameter variations with light) need to be known. Device parameters typical for 1μmx500μm GaAs MESFETs under operational bias conditions were used and the more easily obtained circuit parameters were calculated.(5)

Gate-to-source capacitance variations with light were obtained by taking 1MHz measurements with source-to-drain grounded. Typical results of this measurement are shown in Figure 4, which indicates that C_{gs} increases with photoillumination due to an increase in the effective space charge density in the gate depletion layer (and not due to a change in built-in potential). This is attributed to hole trapping in the gate depletion layer, indicating that the difference in frequency variation with light intensity between the GAT 5-01 and HFET-1000-02 may be caused by different hole trap densities.

With this model, the predicted frequency change with light is two to three times larger in magnitude than experimentally measured in the CS and CG circuits, with the deviation greater in the CD mode as indicated in the last column in Table 3. The greater error in the CD mode is attributed to performance of the gate bias circuitry below 5 GHz. In other CD oscillators operating above 6 GHz, a 2 to 3 factor in difference between measured and calculated frequency tuning was observed. This indicates that the circuit model predicts well the relative frequency sensitivity to photoillumination in the three circuit modes, but predicts a greater frequency sensitivity than actually measured. This is mainly attributed to the assumptions of negligible series feedback and the use of C_{gs} variations with light measured 1MHz with source-to-drain shorted, although further analysis is needed to verify this hypothesis.

Summary and Conclusions

In this paper experimental results on the photosensitivity of C and X band GaAs MESFET oscillators have been presented. The CS and CG mode oscillators have an order of magnitude more sensitivity to light than the CD oscillators, principally due to the sensitivity of oscillator frequency to C_{gs}. A circuit model based upon the self-starting condition indicates qualitative agreement with measured data, although model refinement is necessary before the possible effect of other device parameters on light sensitivity can be determined. The principal tuning mechanism is attributed to hole trapping in the gate depletion layer, resulting in an increase in effective space charge density with illumination. A different oscillator tuning dependence upon light intensity is hypothesized to be caused by different hole trapping densities in the device.

Acknowledgements

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References

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Device	D.C. Operating Point V_{DS}, V_{GS}, I_D (V) (V) (mA)	Power Output (dBm)	Oscillation Frequency (GHz)	RF Efficiency (%)	Δf with Nominal Intensity (MHz)	$\Delta f/f_o$ (%)
NE-24400-01	3 20, -0 88, 16.5	+2	4.3	3.0	-40	-0.9
HFET-1000-01	3 0, -1.1, 20 8	+2	3.6	2 5	-140	-3 9
GAT 5-01	3.0, -1.66, 10.9	0	4.2	3 0	-130	-3 1
	3 0, -1.80, 9.0	0	8.0	3.7	-175	-2 2

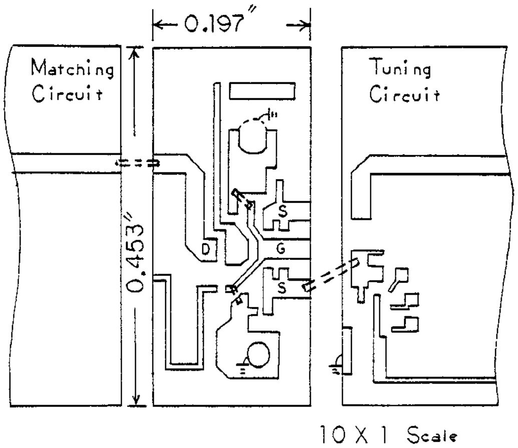
Table 1 Common Source Oscillator Photoinduced Frequency Change

Device	D.C. Operating Point V_{SD}, V_{GD}, I_D (V) (V) (mA)	Power Output (dBm)	Oscillation Frequency (GHz)	RF Efficiency (%)	Δf with Nominal Intensity (MHz)	$\Delta f/f_o$ (%)
NE-24400-01	-3.34, -4.73, 8 0	+3	4.78	7.5	-6	-0 1
HFET-1000-01	-3.0, -4 5, 14 2	+6	4 35	9 4	-6	-0.1
	-3.0, -4 5, 14.2	+5.5	8 90	8 3	-35	-0.4
GAT 5-01	-3 0, -4 5, 13.8	+5	4.60	7 6	-6	-0.1
	-3.0, -3.9 24.5	+3.5	9 65	3 0	-20	-0.2

Table 2 Common Drain Oscillator Photoinduced Frequency Change

Mode	D.C. Operating Point			Power Output (dBm)	Oscillation Frequency (GHz)	RF Efficiency (%)	Δf with Nominal Intensity (MHz)	$\frac{\Delta f}{f_o}$ (%)	Δf Calculated (MHz)
	V_{DS}, (V)	V_{GS}, (V)	I_D (mA)						
CS	3.00	-0.74	18.1	10	9.86	18.	-190	-1.9	-280
	3.00	-0.75	25.2	10	10.10	13.	-170	-1.7	-260
	V_{SD}, (V)	V_{GD}, (V)	I_D (mA)						
CD	-3.38	-3.92	16.1	10	4.93	18.	-6	-0.1	-30
	-3.08	-3.92	35.7	13	4.20	18.	-6	-0.1	-65
	-3.30	-3.98	17.4	9	4.21	14.	-15	-0.4	-65
	V_{DG}, (V)	V_{SG}, (V)	I_D (mA)						
CG	3.16	0.77	16.7	9	5.60	20.	-75	-1.3	-220
	3.43	0.77	25.3	10	6.42	15.	-65	-1.0	-220

Table 3 Performance of HFET-1000-02 in CS, CD and CG Modes (with Identical Tuning Circuit)



Device Mounting Section Drawing Plus
Part of Tuning/Matching Sections for
MESFET Oscillator Circuit Layout No. 2

Figure 1 Planar Device Mounting Suitable for CS, CD and CG Oscillators

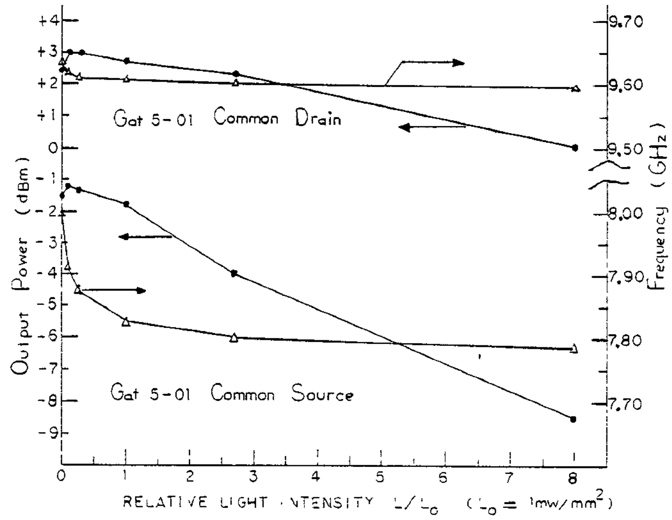


Figure 2 Power and Frequency Dependence upon Light Intensity for GAT 5-01 at X-Band

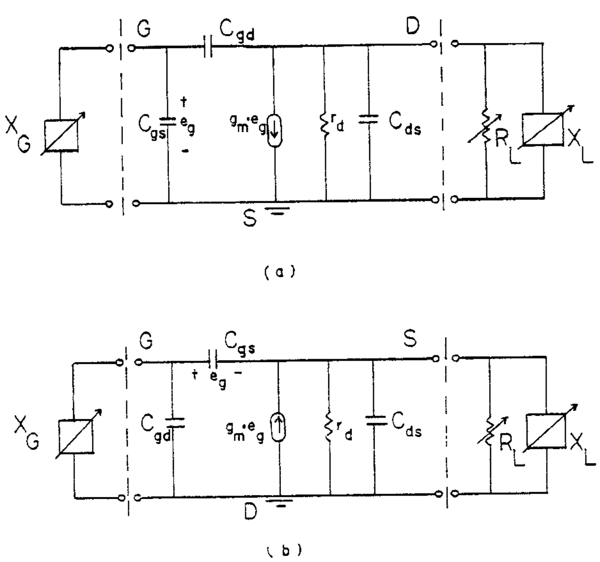


Figure 3 Oscillator Equivalent Circuit Models for a) CS and b) CD modes

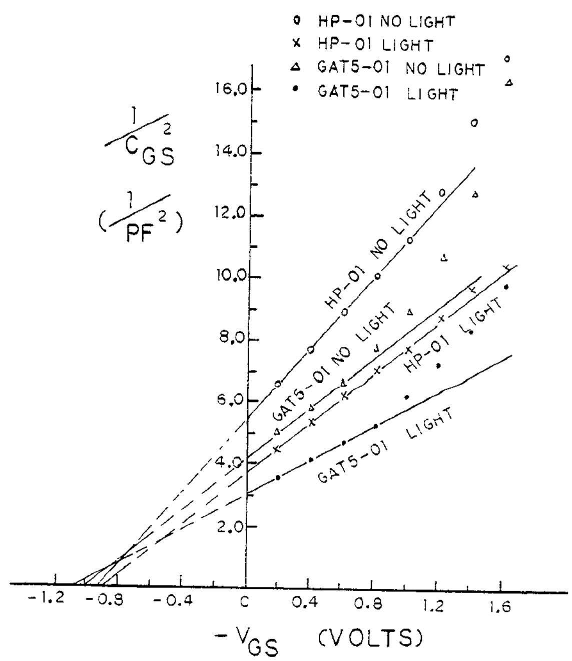


Figure 4 Capacitance - Voltage Characteristics of GaAs MESFETs with and without Light (frequency = 1MHz, V_{DS} = 0 volts)