A DIRECT OPTICAL INJECTION LOCKED 8 GHz MMIC OSCILLATOR

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ABSTRACT

For the first time the optical injection locking behavior of a monolithic integrated HFET-oscillator has been investigated. The monolithic integration is an important step towards the implementation of optically controlled oscillators in phased array antenna systems. The oscillator was designed to operate at 8 GHz. The gate and source terminals of the HFET were biased at 0 volt through coplanar lines, which also served as a feedback and resonator circuit. The active region of the device was illuminated by a pigtailed laser diode modulated at about 8 GHz so that the oscillator circuit could be optically injection locked. The experimental results show the optical locking behavior of the oscillator. A direct comparison between optical and electrical injection locking is possible.

INTRODUCTION

Fundamental work in the field of injection locking has been carried out by Adler [1], Kurokawa [2], and Stover [3]. The well known Adler's equation,

$$\Delta f = f_0/Q_{ext} \sqrt{(P_{inj}/P_{out})} ,$$

describes the relation between the locking range Δf and the injected power. Here f_0 represents the free running oscillator frequency, Q_{ext} the circuit's external Q-factor, P_{inj} the input power, and P_{out} the output power.

Applying this equation to optical injection locking, de Salles [4] found a fair agreement between calculated and measured data. A more recent work about optical injection locked oscillators was published by Esman et al. [5].

Many different ways of increasing the locking range have been proposed. Important contributions towards this have been given by Herczfeld, Daryoush, Madjar, Berceli et al. [6, 7, 8], who used a photodiode to convert light into electrical energy. By amplifying the electrical signals and coupling them to the oscillator a large locking range can be achieved. This method is so sensitive that even the second and third harmonics can be used for locking (indirect subharmonic locking).

Recently, Kása, Baranyi et al. [9, 10] presented valuable experimental and theoretical results on optical tuning and synchronization of MESFET oscillators.

OSCILLATOR CIRCUIT

The oscillator was designed using the EEsof software Touchstone. A simple oscillator circuit was chosen (Fig. 1). The gate terminal is shorted to ground by a coplanar waveguide (CPW) with a length of l=2.8 mm, which is an inductance at the frequency of 8 GHz. Conditioned by the FET geometry, the source is dc-grounded through two symmetrical 50 Ω CPWs with l=4.6 mm each. By a 50 Ω coplanar line (l=2.3 mm) both, the drain bias is supplied and the output signal is measured.

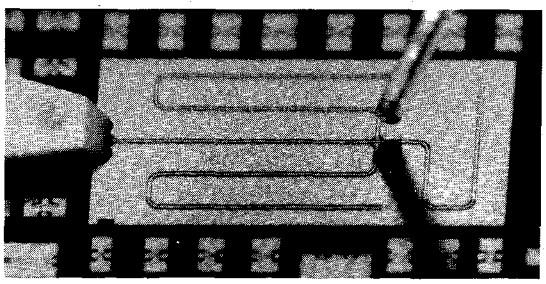

Fig. 1: Optically controlled 8GHz-MMIC-oscillator.

The active device is an HFET with a gate length of 0.25 µm and a gate width of 2x50 µm, depicted in Fig. 2. The U-gate structure was chosen to make optimal use of the non-focussed light spot. The transistor's S-parameters were known from earlier measurements and implemented in the software.

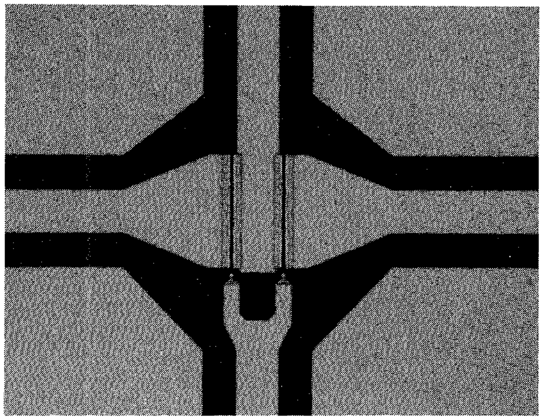

Fig. 2: Microscopic view of the U-gate HFET.

EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 3. The oscillator was measured on a Cascade wafer prober. The dc power was supplied by an HP4145B semiconductor parameter analyzer connected to an HP8515A test set. A power divider splited the output power between the HP54120A oscilloscope and the HP8569A spectrum analyzer.

The SL1020s Ortel laser diode with a single mode fiber pigtail was biased in the linear range using an LDX3620 current source and an HP11612A bias network. The signal from the HP8359A sweep oscillator was

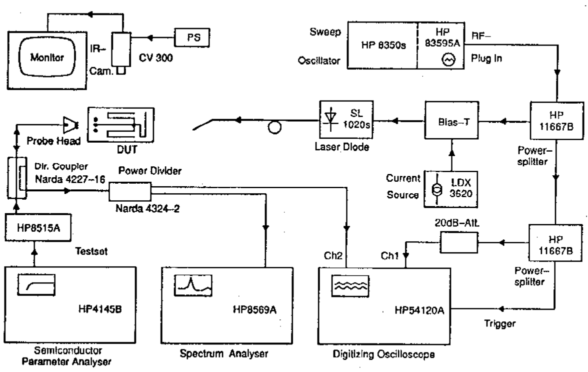

Fig. 3: Experimental setup.

connected to the laser through a bias T and to the oscilloscope. The position of the light spot was observed by an infrared camera with a monitor. The fine adjustment of the position of the light spot was accomplished by observing the DC drain current of the HFET through the HP4145B.

EXPERIMENTAL RESULTS

In introductory experiments the response in the transistor's DC current to the laser bias without modulation was observed. The change in the drain current, Fig. 4, is mainly due to the photogeneration of electron-hole-pairs.

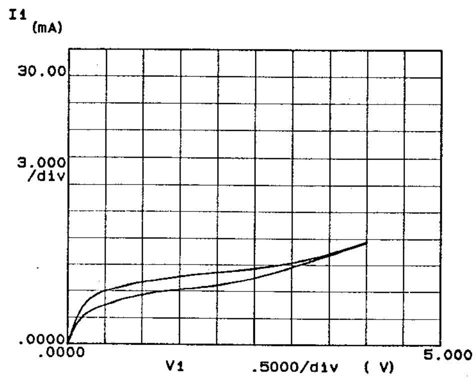

Fig. 4: Drain current versus drain bias with (upper curve) and without illumination (lower curve).

Then the change of the frequency of the oscillation with the intensity of the light was examined. A tuning range of about 15 MHz was found. The oscillator output signal exhibited a small jitter in frequency, which was independent of DC bias and illumination.

The frequency range for injection locking mode was determined by means of the sweep oscillator. The frequency range for locking was about 1 MHz (Fig. 5) at an optical peak-to-peak laser power modulation of P_{pp}=1.9 mW. The reason for the small range will be discussed below. The phase shift of the oscillator output signal depends on the average optical laser power P_{ave}, which is adjusted by the laser bias (Fig. 6). Because of the hopping in the oscillator's frequency, it was impossible to observe the predicted phase shift range of ±90°.

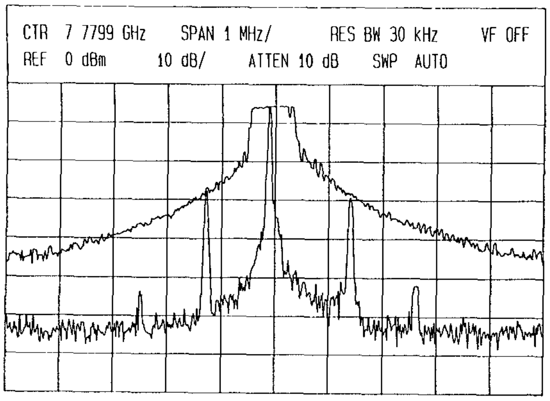

Fig. 5: Locking range (upper curve) and spectrum of the unlocked oscillator (lower curve).

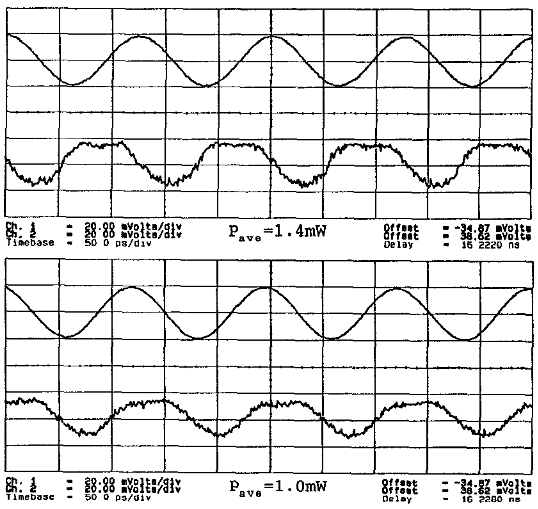

Fig. 6: Generator (upper traces) and oscillator output signals near upper and lower end of locking range ($\Delta\phi \approx 150°$).

DISCUSSION

The frequency of direct locking is mainly limited by the characteristics of the laser. The major problem using the method of direct optical injection locking is the low coupling efficiency between the optical and electrical signal. The light spot from the tip of the fiber is elliptic, the shape of the ellipse depends on the position and orientation of the fiber. It is possible to optimize the light spot so that the intensity over the entire absorbing parts of the transistor, i.e. the space between the source and the gate and between the gate and the drain, is almost uniform. The transistor geometry, however, does not allow more than approximately 3.5 % of the light to enter the active region. An additional reduction in the efficiency of absorption results from the finite thickness of the transistor material. Less than 5 % of the incoming light will be absorbed in the thin InGaAs channel of the transistor. The combination of these two restrictions results in the low coupling and therefore small locking range.

The maximum range of phase shift, however, is independent of the locking range. At the ends of the locking range the phase shift will be +90° and -90°, respectively. Obviously, if there is a jitter of the oscillator's free running frequency, the resulting phase error will be relatively smaller when the locking range is large.

CONCLUSION

In this paper, we have described the optical locking behavior of an MMIC oscillator working at a frequency of 8 GHz. Our simple circuit makes use of coplanar waveguides to satisfy the oscillation condition and to supply the voltage. A description of the active device and the oscillator circuit is given. An estimate of the power of the absorbed light has been made. The optical locking behavior was shown by the experimental results.

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