A Pulsed Microwave Oscillator Using Optically Controlled Active Feedback

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***Abstract*— An optically controlled microwave oscillator is demonstrated using MMIC compatible design techniques. The oscillator uses an optically controlled active inductor as a tunable feedback element in a two-port common gate FET circuit configuration. Experimental results are presented for a pulsed mode of operation that is triggered by illuminating the active feedback circuit.**

I. Introduction

There has been increasing activity in the development of optically controlled microwave circuits due to the small size, lightweight, and immunity to EMI associated with optical technology [1]. In addition, several approaches have been proposed to monolithically integrate optical and microwave functions in GaAs to achieve the full benefit of hybrid optical/microwave circuits [2]. In order to insure MMIC compatibility, the MESFET should be used as the optically sensitive microwave circuit element since it is the basic active MMIC device. However, the MESFET photoresponse consists primarily of transconductive and capacitive effects which occur simultaneously in the device under optical illumination [3]. Unfortunately, the simultaneous occurrence of these effects can cause undesirable circuit performance including power variation with oscillator tuning, insertion loss variation with phase shift, and Q variation with filter tuning. Due to these difficulties, as well as the lack of an intrinsic inductive photoresponse in the MESFET, the use of an optically controlled active inductor has recently been proposed to provide an additional degree of freedom in the design of optically controlled microwave circuits [4]. The active inductor is MMIC compatible and is tuned by the direct optical illumination of one of the MESFET's comprising the circuit. In this letter, the optically controlled active inductor is incorporated in the design of a two-port common gate FET negative resistance oscillator. Pulsed operation is demonstrated in a nonoptimized circuit configuration which shows significant improvement in the optical power requirements and fall time transient response over previously reported optically pulsed oscillators.

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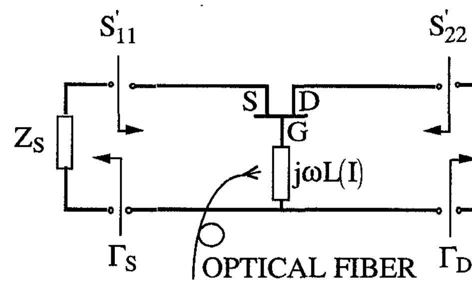

Fig. 1. Two-port negative resistance oscillator with optically controlled active feedback.

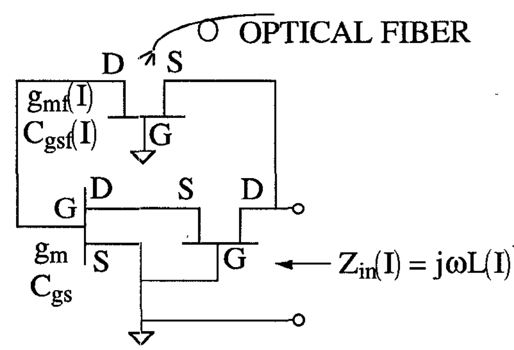

Fig. 2. Optically controlled active feedback network.

II. Optically Pulsed Oscillator

The block diagram of the common gate FET oscillator under consideration is shown in Fig. 1 where inductive series feedback is required to obtain negative resistance [5]. The inductive feedback may be achieved from the bond wire connecting the gate to ground at higher frequencies, however, a larger inductance is needed at lower frequencies which necessitates the use of lumped or distributed circuit elements. In a MMIC oscillator realization, the use of spiral inductors or distributed circuit elements can provide the required inductive feedback, however, both of these techniques require significant real estate and provide fixed feedback only. Therefore, the optically controlled active inductor is used as the series feedback element which significantly reduces the circuit size while at the same time providing a means for optical control.

The optically controlled active inductor consists of a cascode FET pair and a common gate feedback FET as shown in Fig. 2 [4]. The circuit input impedance in the active mode of operation is given by the following expression where I denotes

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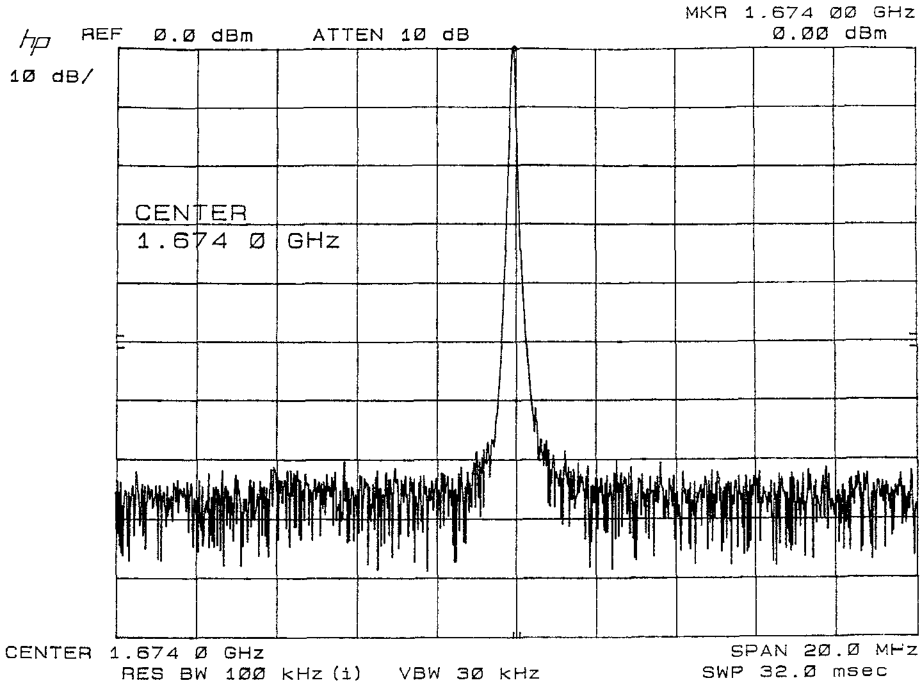

Fig. 3. CW oscillator spectrum.

the dependance on optical intensity [6]:

$$Z_{in}(I) \approx \frac{j\omega C_{gs}}{g_m g_{mf}(I)}, \quad \frac{\omega C_{gs}}{g_m}; \quad \frac{\omega C_{gs}(I)}{g_{mf}(I)} << 1, \tag{1}$$

where C_{gs} = gate to source capacitance of each FET in the cascode pair, g_m = transconductance of each FET in the cascode pair, and $g_{mf}(I)$ = transconductance of the illuminated feedback FET

The steady state oscillation conditions for the circuit in Fig. 1 are given by [5]:

$$\Gamma_S S_{11} = 1, \tag{2}$$

$$\Gamma_D S_{11} = 1, \tag{3}$$

where Γ_S = reflection coefficient for the source to ground load and Γ_D = reflection coefficient for the drain to ground load.

Since the oscillation condition is dependant on the instantaneous value of the feedback impedance, pulsed operation may be obtained by appropriate tuning of the optically controlled active inductor to alternatively create and destroy the negative resistance condition.

III. Experimental Results

The optically controlled oscillator was built in a hybrid MIC construction on a 1″ × 1″ alumina substrate utilizing an NE25000 dual gate FET for the active inductor cascode pair, an NE71000 FET for the active inductor feedback FET, and an NE72000 for the common gate oscillator FET. A series combination of 13 nH of fixed and 5 nH of active inductance was used to provide the 18 nH of inductive feedback required for the desired oscillation frequency of 1.67 GHz. A 835-nm pigtailed LED was positioned over the NE71000 FET with a micropositioner and modulated with a pulse generator to provide the optical tuning. A 12-ms pulse width with an associated duty cycle of 20% was used as the LED modulation waveform. The NE71000 was biased near the pinchoff region in the dark state which destroys the active inductance and the steady state oscillations. The pulse generator waveform was then adjusted to provide sufficient optical intensity to tune active inductance to a value that will permit oscillations for the duration of the light pulse. This value of inductance was approximately 5 nH and was obtained with only 300 μW of peak optical power. An external amplifier with 15dB of gain was used to amplify the oscillator output power to 1 mW since, for this initial proof-of-concept design, an integrated buffer amplifier stage was not used and no attempt was made to optimize the output power. Fig. 3 shows the CW spectrum of the oscillator in the on stage (with illumination). The top trace of Fig. 4 depicts the input signal used to modulate the LED and the bottom trace of the same figure shows the crystal detected envelope of the pulsed microwave signal. The envelope has a measured 10–90% rise time of 97 μs and fall time of 295 ns. A significant improvement in the fall time is achieved over previously reported results which are in the millisecond range due to the long excess carrier lifetimes associated with traps in the MESFET [7]. Since the oscillator operating point in the present experiment is selected near the edge of the negative resistance region, only a small change in the series feedback inductance is required to switch between the oscillation and stable regions. Therefore, oscillations are quenched as soon as the required feedback condition is destroyed. While the full transient response time of the MESFET in the active inductor may be quite long (in the millisecond range) due to excess carrier dynamics, the incremental change in inductance required in the circuit to stop oscillation may be achieved in

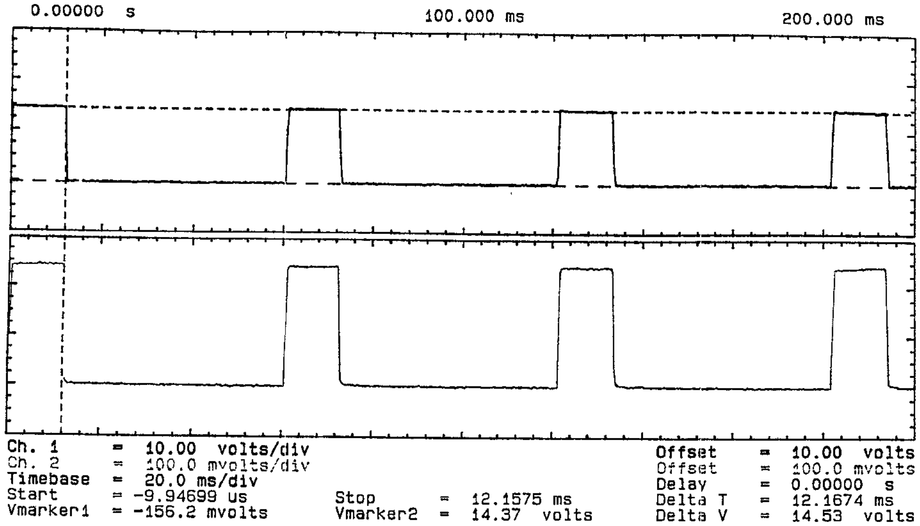

Fig. 4. Pulsed waveform: Top trace — LED modulation waveform bottom trace — Crystal detected pulsed microwave signal.

considerably less time with proper electrical and optical bias. In other words, the circuit and the biasing are designed to overcome the speed limitation of the device. It should also be noted that the internal photovoltaic effect was used to provide the desired optical response of the active inductor thus avoiding the slow RC time constant associated with the use of an external gate resistor [8]. Similar improvements are expected in the rise time response by optimizing the bias and optical illumination conditions.

IV. Conclusion

An optically controlled pulsed oscillator is demonstrated using optical tuning of an active inductor feedback network. Optical illumination is used to switch between the inductive and cutoff modes of operation of the network to initiate and terminate oscillations respectively. The experimental results demonstrate a significant improvement in the oscillator fall time transient response because the operation of the oscillator is primarily determined by the instantaneous feedback impedance. In this configuration, the undesirable effects associated with long excess carrier lifetimes in the MESFET are minimized by selecting the electrical and optical bias points near the boundary of the negative resistance region resulting in a faster circuit response. Additional improvements are expected in the rise time response, output power, and bandwidth with slight design modifications. These results demonstrate the application of the optically controlled active inductor to design MMIC compatible hybrid photonic-microwave circuits.

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