OPTICALLY CONTROLLED K-BAND OSCILLATOR

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ABSTRACT

PIN photodiodes play an important role in detection of modulated light in fiberoptic links. However these devices are essentially junction devices, with bias dependent capacitance very similar to varactor diodes. Particularly under proper biasing conditions, junction capacitance of these devices can be changed by light illumination. This paper reports results of tuning and frequency modulation experiments of a 24.5GHz oscillator configured with a PIN photodiode as the tuning element. Both electrical and optical tuning were investigated, resulting in tuning range of few hundred MHz at K-band.

INTRODUCTION

Optoelectronic devices are an integral part of many high-speed fiber optic networks. Most of the optoelectronic devices are based on the p-n junction, and among them semiconductor laser diodes and PIN photodiode are commonly used in many integrated optoelectronic sub-systems. In fact optoelectronic integrated technology (OEIC) has reached a level of maturity, whereas integration of PIN photodiodes with FET amplifiers are routinely performed. The photoconductive characteristic of the p-n junction is used, in such a configuration, where the modulated photons are absorbed in the depletion region (i region) of the device. However, p-n junctions manifest other circuit characteristics such as capacitance modulation, as prominently experienced in varactor diodes. Since the characteristics of PIN photodiodes are not any different from microwave p-n junction based switches and modulators, these optical devices could also exhibit changes in junction capacitance as a function of biasing. This change in capacitance can be exploited in a similar fashion as are varactor diodes when used in a number of microwave applications. Of particular interest is frequency tuning and modulation of oscillators (1).

Conversely, under appropriate biasing conditions the PIN diode's junction capacitance can be controlled by light, resulting in phase shifting(2) and switching(3) depending on whether capacitive or conductive change of the device is employed. The light dependent capacitance and conductance of the PIN diode is linked to light modulation of the depletion width in the intrinsic layer, which is very sensitive at bias voltages close to zero biasing (2). The same performance can also be expected out of PIN photodiodes, when they are reverse-biased well below the punch-through voltage.

The goal of this paper is to integrate a PIN photodiode in a microwave oscillator circuit to investigate: i) optical tuning of the oscillator, ii) characterization of the performance dependence on the biasing condition, iii) comparison of electrical versus optical frequency tuning of the oscillator.

EXPERIMENTS

A hybrid HEMT oscillator circuit at K-band was fabricated in the common source configuration with an AlGaAs/GaAs hetero-junction PIN photodiode (PDO50-C from Ortel) as a tuning element, as shown in Fig. 1. A self biasing configuration was selected for design simplicity. The oscillation frequency is determined by the phase delay of the transmission line when terminated by the low capacitance of the PIN photodiode at the gate. The gate pad of the HEMT and the p-contact of the PIN photodiode are grounded by an rf choke; the n-contact of the PIN photodiode is biased by a separate power supply. The output of the oscillator is taken directly from the drain with no matching network. The oscillator's output power is 8dBm at 24.71GHz. The junction capacitance of the PIN diode under no illumination is dependent on the biasing voltage, and at zero bias is measured as high as 3pF for reverse-biased potential of 6V, it reaches minimum value of 1pF.

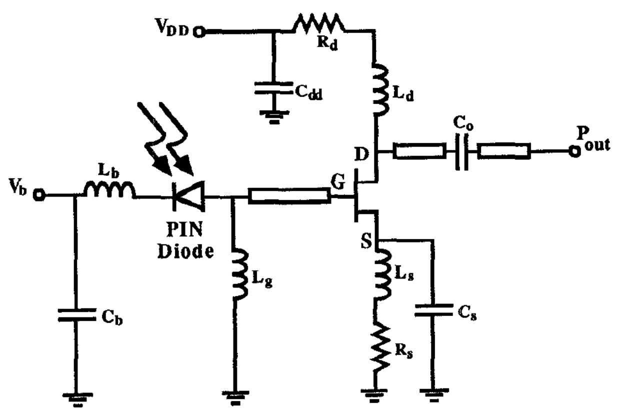

Fig. 1 Equivalent circuit diagram of the optically controlled 24 GHz HEMT oscillator. The PIN diode is employed as an optically controlled capacitor to control the oscillator.

First electrical frequency tuning of the oscillator was investigated. The shift in the oscillator frequency was measured for light and dark conditions when the PIN photodiode was reverse-biased from 6V to a forward bias of 1V. The PIN photodiode was illuminated by a buried-heterojunction (BH) AlGaAs laser light source at 820nm. The laser light was coupled to the photodiode using a multimode optical fiber and the coupled light power was calculated from the detected current and the known optical responsivity of the photodiode. Under illumination of 1mW, the frequency shift was observed on a spectrum analyzer, as shown in Fig. 2. This plot indicates that the oscillation frequency is controlled by the coupled light

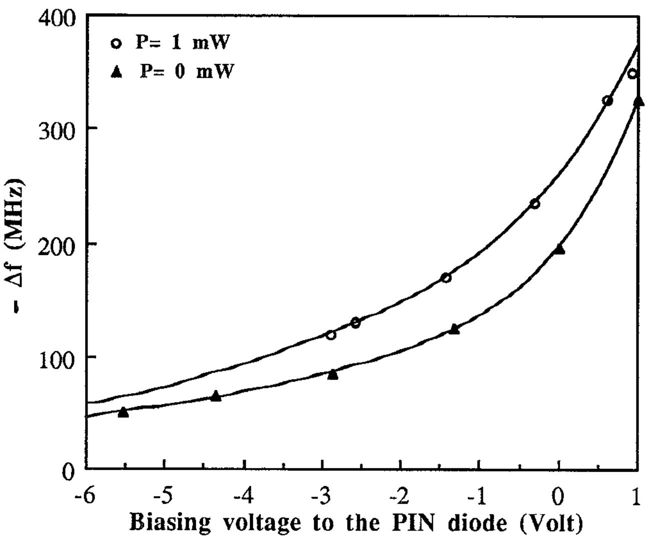

Fig. 2 Frequency shift of the 24 GHz HEMT oscillator as a function of the PIN diode biasing for dark and light conditions.

power. The frequency shift is downward as is expected by increase in the capacitance. The junction capacitance is not only increased by decreasing reverse-bias potential but also is shifted by light power of 1mW.

Next the dependence of oscillation frequency on the light power coupled to the PIN photodiode was studied at fixed biasing levels. Fig. 3 depicts the frequency shift as a function of the PIN photodiode biasing for the various optical coupled powers, ranging from zero to 2mW. The highest frequency shift is observed for bias level of +0.5V at light power level of 1.6mW. The solid line shows the best fit to the data. Similar frequency shifts were also observed for reverse-biased operating points.

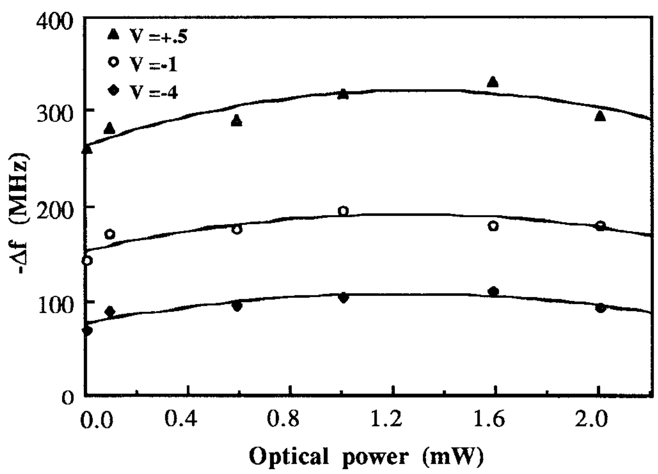

Fig. 3 Frequency shift of the 24 GHz HEMT oscillator as a function of optical power coupled to the PIN diode for three different bias conditions.

To investigate feasibility of the optically induced frequency modulation characteristics of the oscillator, the laser diode was modulated by an rf synthesized generator; the modulated light was then coupled to the PIN photodiode. The PIN photodiode was biased close to the zero biasing, where the highest frequency shift was observed. The results of the FM are rendered in Fig. 4. For modulating frequency of 10MHz, the FM modulation index of $\beta \approx 2$ was achieved (cf. Fig. 4), whereas for modulating frequency of 30MHz, $\beta \approx 0.7$ was measured. The frequency modulation was also accompanied by some residual amplitude modulation. The amplitude modulation is caused by the change in forward resistance of the PIN photodiode.

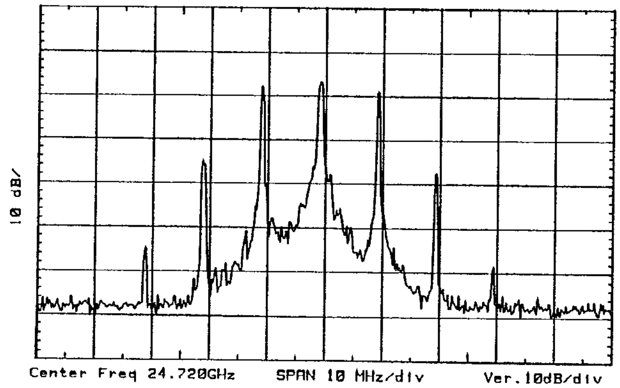

Fig. 4 Broadband frequency modulation (β=2) of the HEMT oscillator by intensity modulation of the optical source. (Horizontal scale of 10 MHz/div. and center frequency of 24.72 GHz.)

DISCUSSION

The preliminary result reported in this paper indicates that PIN photodiodes can be employed for frequency tuning and modulation of microwave and millimeter wave oscillators, in a similar fashion as the varactor diodes are employed in VCO. This method of frequency control optical tuning of the oscillator could be labeled as OCO. The major difference of this approach as opposed to the previously reported work on the optical control of the microwave circuits is that in the past, optical control were realized by interacting light with the solid state microwave devices, whereas in this work solid state devices tailored for optical functions are integrated to the microwave circuits to achieve various control functions. These control functions in the optical devices are realizable because of the similarity of the high-speed optical and microwave devices.

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