InP-BASED GILBERT CELL PHASE DETECTOR FOR GENERATION OF STABLE DENSE WAVELENGTH DIVISION MULTIPLEXING CHANNEL OFFSETS USING AN OPTICAL PHASE-LOCKED LOOP

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ABSTRACT

A Gilbert Cell phase detector for use in an integrated optical phase-locked loop (OPLL) was designed and fabricated using p-i-n/HBT layer structure optimized for photoreceivers. This phase detector was employed in an OPLL designed for producing stable dense wavelength division multiplexing (DWDM) channel offsets. Offsets of 1.4 to over 10 GHz were achieved.

INTRODUCTION

As demand for higher communication speed and capacity grows, new methods need to be developed to take advantage of the large bandwidth potential of optical fibers. One important technique that is already in use commercially is wavelength division multiplexing (WDM), in which multiple wavelengths are transmitted on the same fiber. The widespread use of wavelength division multiplexing becomes even more attractive with the development of the erbium-doped fiber amplifier (EDFA), which can amplify multiple wavelength channels simultaneously without repeaters. However, due to the EDFA gain profile, a limit is set on the range of wavelengths that can be used, requiring channel spacing to be reduced in order to provide additional channels. The most dense standard currently in use for dense wavelength division multiplexing (DWDM) is the International Telecommunications Union (ITU) standard of 100 GHz channel separation (about 0.8 nm at 1.55 μm). Research is currently being done on

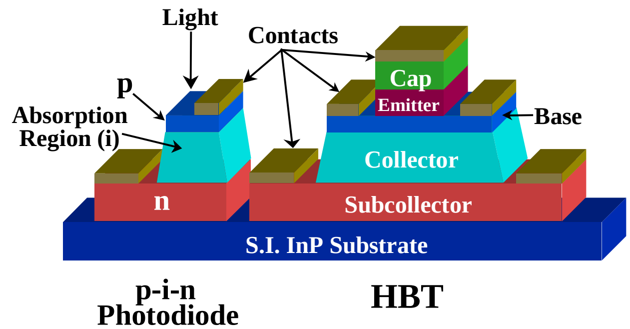

Figure 1: Cross section of the p-i-n/HBT structure

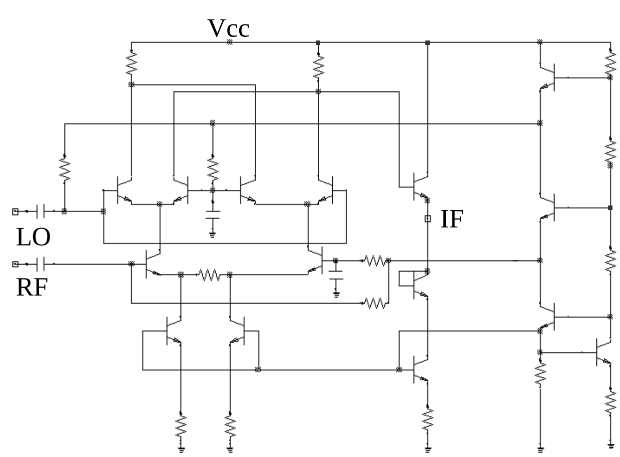

Figure 2: Gilbert Cell circuit diagram

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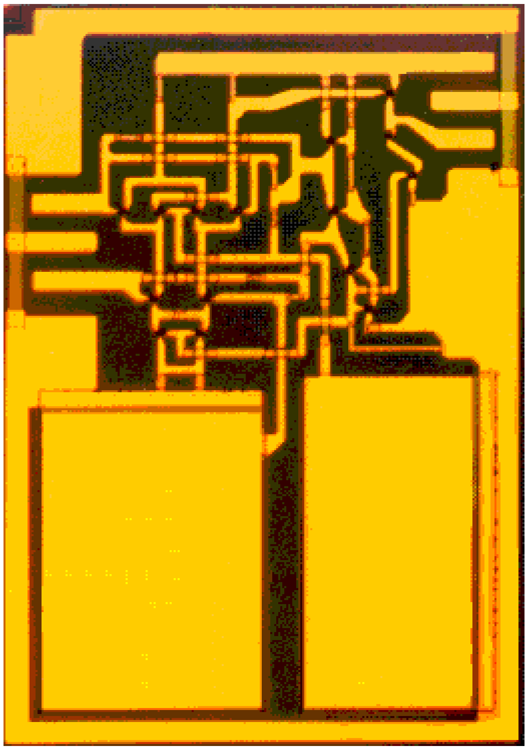

Figure 3: Photomicrograph of Gilbert Cell phase detector

50 GHz separations, while separations of 25 GHz and smaller are being discussed in order to increase the maximum number of wavelength channels. At these very small wavelength separations, improved stabilization of the laser wavelengths will be necessary. Our optical phase-locked loop (OPLL) has already demonstrated stabilization of wavelength separations from 3.00 to 27.11 GHz [1] using a p-i-n/HBT photoreceiver as the optical detector in the loop. The current paper discusses the design and testing of a Gilbert Cell phase detector made with the HBT process that is planar-compatible with the p-i-n detector of the photoreceiver already demonstrated in an OPLL and an OPLL experiment using the Gilbert Cell as the phase detector.

TRANSISTOR DESIGN

In order to make practical the use of OPLLs to control channel spacing for DWDM systems, monolithic integration is necessary to reduce both cost and loop delay. This integration scheme requires both photodetectors (for optical to electrical signal conversion) and high-speed transistors (for amplification) in a compatible fabrication process. By using heterojunction bipolar transistor (HBT) technology, a p-i-n/HBT front-end photoreceiver can be fabricated [2] and can be used in the OPLL as a high-gain optical detection device. The base-collector-subcollector layers of the HBT serve as the p-i-n diode. Thus a high-speed, low-noise transistor is monolithically integrated with a high-performance photodiode, as shown in Figure 1. We have demonstrated photoreceiver circuits with measured modulation bandwidth f_{-3dB} = 19.5 GHz, and an estimated sensitivity of -18.7 dBm at 10 Gb/s for a bit error rate of 10^{-9} [3]. The InP-based HBTs used in this process have f_T of 67 GHz and f_{max} of 120 GHz. The material was grown by molecular beam epitaxy and consists of an $In_{0.53}Ga_{0.47}As$ base and collector regions and an $In_{0.52}Al_{0.48}As$ emitter layer. The corresponding transistor model was used in the Gilbert Cell design.

GILBERT CELL DESIGN AND TESTING

For the present study, A Gilbert Cell was chosen as the phase detector due to the gain it provides. The increased loop gain increases the static stability of phase-lock. A standard Gilbert Cell design was used with an emitter follower for decoupling. An on-chip bias circuit was included. The basic Gilbert Cell phase detector circuit diagram is shown in Figure 2, and a photomicrograph of the processed circuit is shown in Figure 3. Circuit designs allowing for external biasing of the Gilbert Cell phase detector and a monolithic integration of the photoreceiver and Gilbert Cell have also been fabricated. The phase

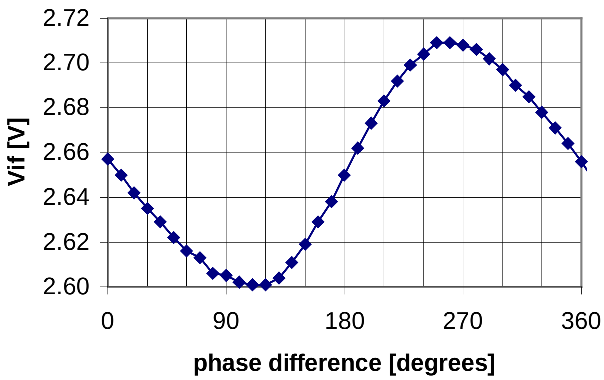

Figure 4: Gilbert Cell phase detector gain K_d at 5 GHz

detector's gain shown in Figure 4 was measured as K_d = 0.83 mV/degree. This was comparable to the gain obtained for the commercial phase detector previously used in the OPLL test bed. The measurement was made at 5 GHz, and the LO and RF powers were approximately +12 dBm and –4 dBm, respectively. Based on this result, the loop gain is sufficient for phase-locking the lasers.

OPLL EXPERIMENTAL SETUP

An OPLL has been constructed. Figure 5 shows the experimental setup of the OPLL. Two temperature-stabilized 1.55 µm 3-section distributed feedback (DFB) lasers are heterodyned with a fiber coupler onto photodetector 1, followed by a low-noise amplifier (LNA). The summed linewidth of the

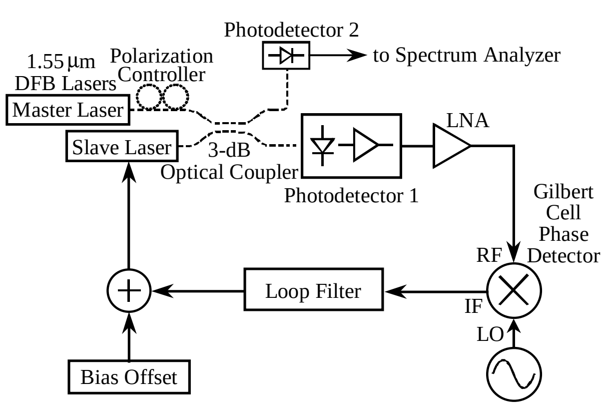

Figure 5: OPLL experimental setup

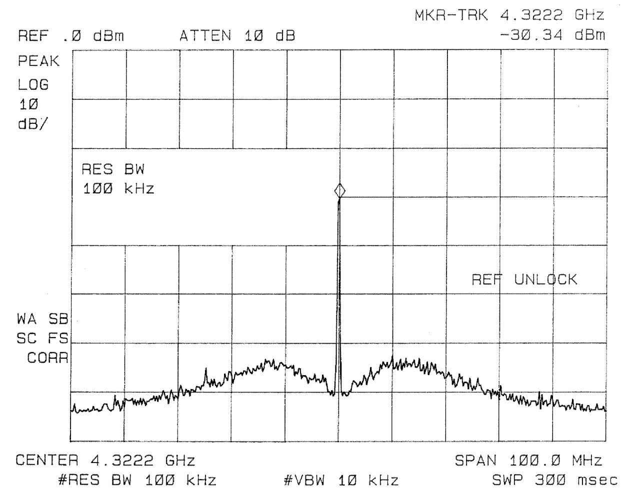

Figure 6: Locked spectrum, center frequency 4.322 GHz, vertical scale 10 dB/div, horizontal scale 10 MHz/div, RBW 100 kHz, VBW 10 kHz

free-running lasers is 3 to 4 MHz, as measured with a spectrum analyzer. 65 dB optical isolators are used between the lasers and the optical coupler in order to avoid an increase in free running linewidth [4]. The phase of the amplified electrical signal is compared with a reference signal from a sweep oscillator using a Gilbert Cell as a phase detector. Due to the difference in voltage between the Gilbert Cell phase detector output and the laser input, and in order to increase the current driving capacity, an external emitter follower with a silicon bipolar RF transistor was used as a bias offset circuit between the Gilbert Cell and the slave laser. The phase difference is then fed back to the slave laser through a passive loop filter. A modified first-order loop [5] is used as it is less sensitive to loop delay than second-order loops [6].

RESULTS

Figure 6 shows the spectrum of the beat signal when locking was achieved with the Gilbert Cell acting as the phase detector, as measured by the electrically isolated photodetector 2. The circuit was phase-locked at various frequency offsets from 1.4 GHz to greater than 10.0 GHz. The hold-in range was measured as approximately 0.8 GHz. Due to a large difference between the β current gain of the original process runs that were used to characterize the HBTs and the HBT process runs with the OPLL mask, the bias circuit did not produce optimum bias voltages. As a result, the Gilbert cell had appreciable conversion loss. New Gilbert Cells have been processed with higher quality material, which should improve the circuit performance. Detailed testing will be performed.

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