Photonics Integration for THz Generation

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Abstract. *The concept of a photonic THz generator is introduced, focusing on the optical part of the phase locking section of the photonic system. Different approaches to the integration of this element of the THz source are discussed, namely hybrid and monolithic integration, showing some initial results.*

1. Introduction.

THz signals are conventionally defined as ranging between 100 GHz and 10 THz. In the past few years THz signals have attracted considerable attention due to their very wide range of potential applications, which include ultra-high bit-rate wireless communications, security screening and radio-astronomy [1]. At present a major limitation in wider exploitation of systems working at these frequencies is their lack of portability and frequency agility. Commercially available sources of THz radiation are mostly based on femtosecond laser systems [2], which are bulky and costly, and which cover the frequency range up to 3 THz typically. A more compact photonic source is the Quantum Cascade Laser (QCL) [3], which offers high power signal at frequencies down to 1.3 THz. However these laser diodes show very limited tuneability, and poor performance at room temperature in the 1 to 4 THz frequency range. Another optical approach to generate THz radiation is by using the so-called photo-mixing [4], or optical heterodyne technique. This offers wide continuous tuneability, but its main limitation is its frequency stability. Nonetheless, it is possible to greatly improve the heterodyne signal stability by locking the beating optical waves to a reference source, typically an Optical Frequency Comb Generator (OFCG), by using the Optical Phase Lock Loop (OPLL) technique. In this case, in order to allow using standard single-mode laser diodes, having linewidths around 1 MHz, it is necessary to be able to produce an integrated THz system, which would offer short optical and electronic delay [5].

This paper starts by introducing a photonic THz system; it then focuses on the OPLL part of the generator, and it presents the different integration approaches of hybrid and monolithic integration, for the optical part of the OPLL. The advantages and disadvantages of the various integration techniques are discussed, and preliminary results are finally shown.

2. The THz Generator.

An optical heterodyne THz generator is shown in Fig. 1. It consists of an OFCG (master), which generates a comb of optical frequencies exactly separated by the supplied microwave reference frequency, two tuneable lasers (slaves), a PLL control circuit, an ultra-fast photodetector and an antenna. In this system the slave lasers are locked to two different lines of the OFCG through a PLL circuit. The two optical signals are combined onto a fast photodetector that generates the THz signal, which is radiated through an antenna [6].

In this work, the chosen locking technique is the OPLL, due to its large locking bandwidth and good signal tracking. A schematic of the OPLL circuit is shown in Fig. 2: light emitted from the master laser and the slave laser is coupled onto a photodetector, to generate an electrical error signal which the PLL circuit compares to a reference source, and then adjusts the slave laser emission to be locked to the master source. In order to guarantee adequate phase noise reduction, in the case of a slave laser with relatively wide linewidth (> MHz), a short loop propagation delay (< ns) is required [5], hence the importance of reducing the loop delay, which can be achieved by integrating the OPLL components onto a single optical circuit.

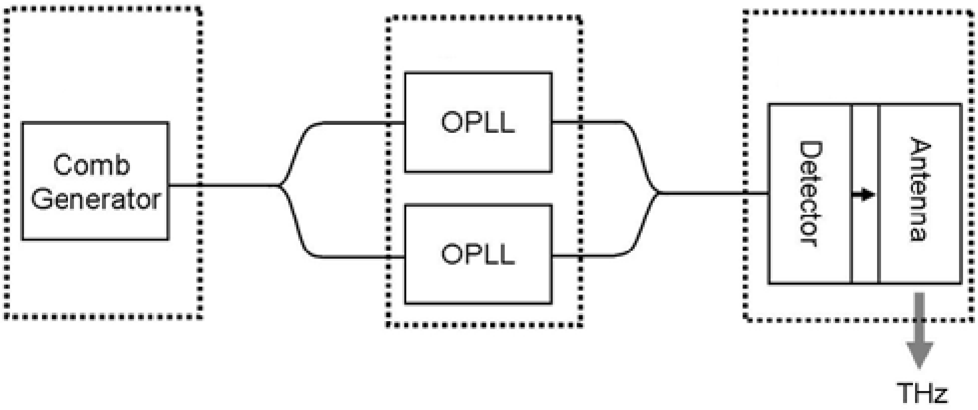


Figure 1: Schematic of the photonic THz generator.

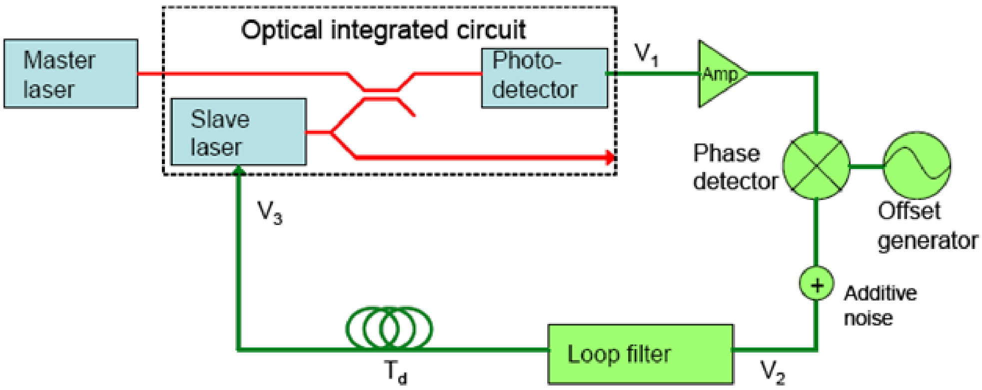


Figure 2: Schematic of the OPLL part of the THz generator, with the optical section within dotted line.

3. The Integrated OPLL: Hybrid vs. Monolithic Approach.

Integration of the various components in the THz generator is necessary to realise a stable portable system, but it is also a serious challenge, due to the need to define several different functionalities on a common platform. The first step to the integration of the whole THz system is to realise integrated single and double OPLL modules. As shown in Fig. 2, the single OPLL optical module consists of a tuneable laser, a photodetector, and passive optical waveguides, connecting the laser to the detector, and to the outside of the module.

In this work two possible routes to integration have been explored: hybrid and monolithic.

The hybrid approach aims at integrating a double OPLL optical element onto a common motherboard. Each optical component is developed independently, on its optimal substrate, then the various elements are combined on a silicon motherboard, which includes passive optical waveguides, combiners, and etched slots, where the active components will be placed [7]. A major advantage of this approach is clearly that the performance of each individual device can be optimised separately.

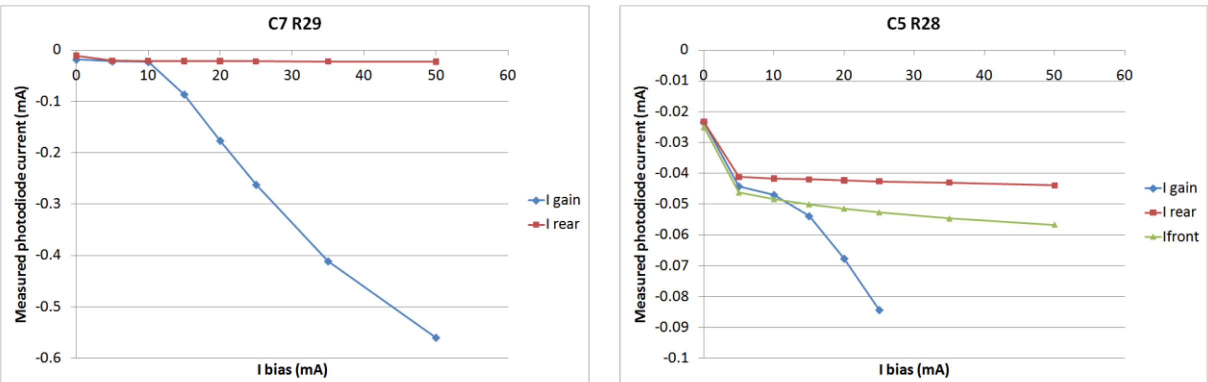
The slave lasers are a set of twin tuneable lasers, which is a pair of closely-spaced DBR lasers designed to give 8 nm tuning range, to be able to access at least half of the comb spectrum, while the photodiodes are designed to have 15 GHz bandwidth, which is approximately half the comb line spacing. Since the operation of the hybrid module is critically sensitive to back reflections, angled interfaces are included to minimise any feedback.

The other integration scheme, the monolithic approach, consists in fabricating all the required optical elements on the same piece of substrate, which in this work is phosphorus quaternary material. The main advantage of the monolithic approach is that it offers the shortest optical path, hence it is very attractive for OPLL applications.

The primary choice made here is to maximise the laser performance, hence the material design is based on the active region requirements. The laser structure is a four-section DBR design, similar to what used for the hybrid module. The detector is designed on the same active structure as the laser, with a ridge waveguide structure, to provide a maximum bandwidth of 10 GHz. All the non-active sections, i.e. phase and grating sections, and passive optical waveguides, are defined by Metal–Organic Vapour Phase Epitaxy (MOVPE) selective area regrowth technique after the first wafer growth of the active material. Also in the case of monolithic integration the design of the active-passive interfaces has to be considered very carefully to minimise back reflections.

The next step in monolithic integration is to further integrate two single OPLL optical modules, to give a monolithic double OPLL chip. This should give a further advantage, since having the two lasers adjacent, on the same chip, will ensure thermal tracking between the two sources, reducing the drift correction requirements on the control loop.

Recently, single monolithic OPLL chips have been fabricated, and their initial assessment looks very promising. Laser testing shows good single-mode operation with 7 nm tuning range. More interestingly, assessment of the photodetectors gives a clear photoresponse, as shown in Fig. 3.The measured photodiode (PD) currents, at -1 V reverse bias, are plotted as a function of the current injected into the different laser sections. Fig. 3a shows a clear threshold behaviour, while Fig. 3b shows how different the detected current is for the case when the gain section is injected with respect to injecting into the passive sections. From these results we can conclude that the diode is effectively behaving as a photodetector; it follows that all the components on the integrated chip are working as expected.



(a) (b)

Figure 3: PD current measurements from the monolithic single OPLL chips (V_{PD}= - 1V).

4. Conclusions.

In this paper recent advances in the area of integrated THz systems were reported. More specifically, the photonic THz generator has been introduced, describing how such a compact THz source would be very appealing, both due to its portability and performance. The paper then focuses on the OPLL section of the system, and it describes two different approaches to the integration of the optical OPLL functionality. Hybrid and monolithic integration strategies are described, and their initial assessment reported, showing some encouraging results.

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