A Terahertz Scanner

R. J. Steed, M. J. Fice, L. Ponnampalam, E. Rouvalis, F. Pozzi, C. C. Renaud, C.-P. Liu and A. J. Seeds

University College London

Abstract: We present a new technique for Terahertz spectrometry which uses a photonic heterodyne system to create and detect THz. The system creates a monochromatic THz beam with a linewidth of less than 1Hz and the frequency of this beam is swept between 20 GHz to 1.4 THz in order to record a spectrum. This offers high power per spectral component. Since the full THz system is based on heterodyne detection, the sensitivity of this system is potentially less than a femtowatt.

1. Introduction

THz frequencies are attracting interest for environmental sensing or communication, but there has been a lack of readily available, compact, THz emitters and receivers. This has begun to be addressed by research in the last decade [1]. Possible compact sources include quantum cascade lasers [2], Gunn diodes [1] and terahertz time-domain spectroscopy using short pulse lasers [1]. One photonic technique for the creation of terahertz signals is the heterodyning of two phase-locked lasers lines in a high bandwidth photodiode [3,4]. Such technique [5] advantageously creates a continuous wave THz signal with stable frequency and extremely high spectral purity.

Here we will discuss a THz scanner which creates and detects a monochromatic beam which is swept in frequency across the THz band to obtain spectroscopic data. In this paper we will discuss the overall design of the THz scanner and our progress at its implementation.

2. System Design

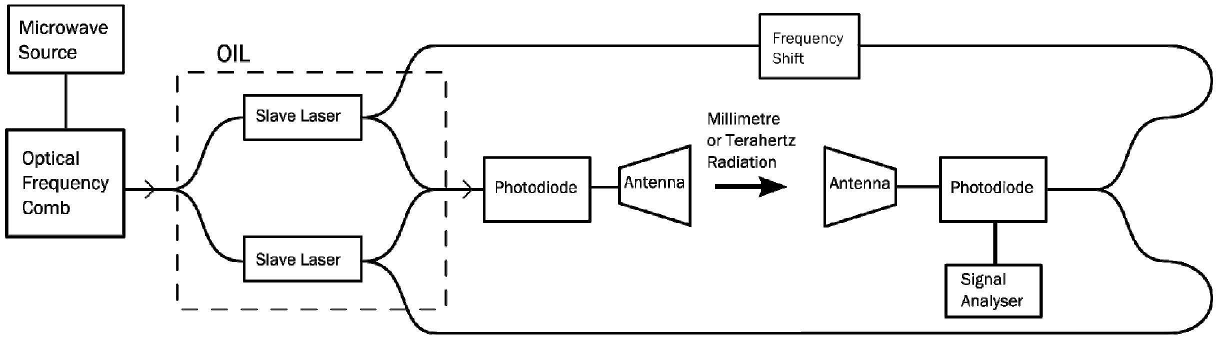

Figure 1: Conceptual design of a THz scanner. The slave lasers are heterodyned to create a local oscillator which is used for both transmitter and receiver. The transmitting photodiode converts the beating signal into terahertz radiation. The receiving photodiode acts as an optically pumped mixer.

Figure 1 shows the overall design of the THz scanner. The THz signal is created by beating the outputs of two semiconductor diode lasers phase locked to a reference source and then rectifying the signal with a high bandwidth photodiode. The receiving photodiode mixes the received THz signal with the optical heterodyne local oscillator (LO) to generate an intermediate frequency (IF) in a range where standard electronic components operate.

The performance of the system rests upon the bandwidth of the photodiodes used and their performance as optically pumped mixers. Uni-travelling Carrier (UTC) photodiodes are designed with an active absorbing medium in the p-doped region, so that the device response depends only on the mobility of the electrons rather than the slower mobility of the holes [6] (Fig.2). UTC photodiodes have been reported with 3dB bandwidths up to >108GHz [6] and with record breaking power at up to 1.5 THz [7]. Recent research has focused on incorporating travelling wave [8] techniques into a UTC photodiode in order to further increase the extracted power at higher frequencies.

The key to the system's sensitivity is that the lasers are mutually phase-locked via an optical frequency comb and so their beat signal contains very little phase noise. This yields a THz signal linewidth of less than 1Hz. Since the THz signal is received via a heterodyne technique, this allows narrow bandpass filters to reject most of the background noise giving a very low noise floor. Considering only thermal noise, an amplification circuit with a noise figure of 3 dB, and defining our mixing conversion loss to be 30 dB with a detection threshold of 10 dB above the noise floor, the minimum power to be detected would be less than 0.1 fW (-130 dBm).

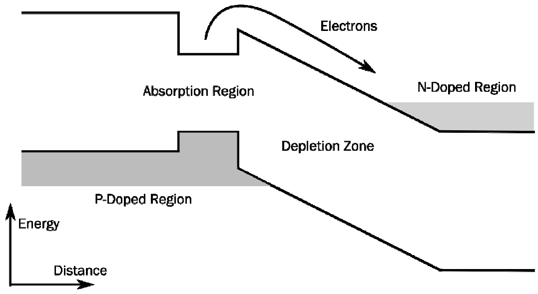

Figure 2 A simplified bandstructure diagram of a UTC photodiode

The frequency comb used for locking the lasers is a short fibre loop containing a phase modulator and an EDFA [15]. This can easily create comb-lines spanning greater than 1.5THz. The loop additionally contains filters, polarisation controllers and a feedback system containing a fibre stretcher which improve the stability of each comb-line's intensity.

The slave lasers are semiconductor laser diodes; either Super Structure Grating Distributed Bragg Reflector (SSG-DBR) [9] or Distributed FeedBack (DFB) types. They are phase locked via optical injection locking [10], optical phase locked loops [11] or a hybrid of the two [12].

The lasers' frequencies can be tuned by controlling the currents to their gain sections or changing each laser's temperature. In the SG-DBR case, additional currents to the mirror and phase sections lead to even greater control and a wider tunable frequency band. Initially, the THz frequency will be swept by shifting the laser frequencies close enough to successive comb-lines for them to become injection locked. Relatively slow feedback loops can be added so that injection locking can be achieved more successfully [12]. In order to tune between the comb-lines, either extra modulation of the comb-lines will be required or optical phase locked loops will be implemented [11]. We aim to be able to scan the complete frequency range in milliseconds [4,13].

3. Current Progress

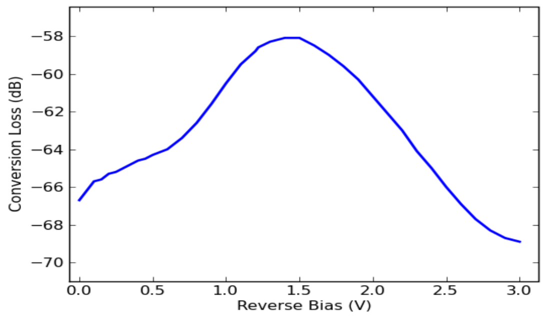

Figure 3: The effect of bias voltage on the conversion loss of a UTC photodiode used as an optically pumped mixer. This data was taken using an 80GHz RF signal of 6.6dBm and a local oscillator of 80.005GHz leading an heterodyned IF signal at 5MHz.

Using a receiving photodiode as an optically pumped mixer has been demonstrated [7]; it receives the local oscillator optically and the THz signal as a time-varying bias. An additional degree of freedom is the DC reverse bias applied to the UTC photodiode. In order for mixing to occur, there must be a non-linear relation between AC bias and the photocurrent; in a simple DC model of a photodiode this only occurs for low DC reverse bias (<1volt). However at high frequencies, good response from the UTC photodiodes requires larger DC bias (~3.5volts) and so there is a trade-off between these two phenomena (Fig. 3). UTC mixing at THz frequency is being investigated. The down-mixed signal is currently chosen to be 5Mhz and is extracted using the UTC bias lines. At 80 GHz, mixing efficiencies of up to -55dB were observed while the mixing efficiency was up to -20 dB at 10 GHz. We believe that the limitation is mainly due to the choice of bias and the frequency response of the devices used, and further investigation is needed to assess the full performance of the device at higher frequencies.

4. THz Communication

Another possible application for the system is to use the available bandwith at THz signal to transmit date wirelessly. This will offer the advantage of higher possible data rate with the draw back of having shorter transmission distances. Using the system we have demonstrated its wireless communication capacity by transmitting successfully a relatively low bitrate (200ksym/s) binary phase shift keyed signal on an 80GHz carrier as seen in the received IF high diagram shown in fig.4. Due to the lack of high speed IF extraction circuitry, the IF was limited at less than 1 MHz, thus limiting the data-rate obtainable.

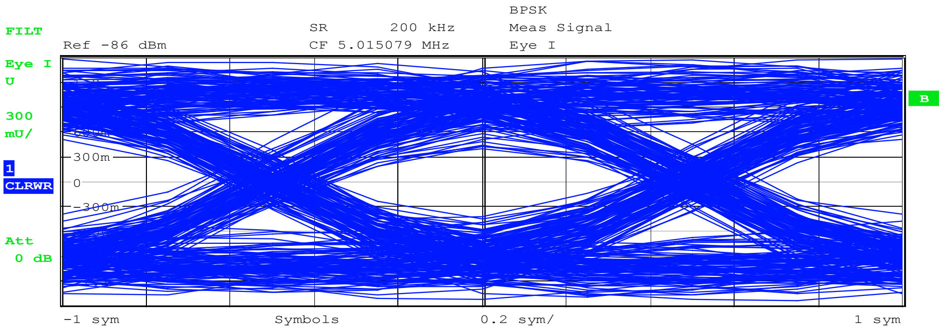

Figure 4: An eye diagram for 200 Ksym/second transmission across a 10 cm gap using an 80GHz carrier.

5. Summary

We have proposed a new type of THz spectrometer which should offer scanning capacity from 100 GHz to 1.5 THz with high spectral resolution (<1Hz) and fast scanning (few ms). This instrument should also offer detection of THz power as low as 0.1 fW. The key proof of concept of the use of an UTC photodector as an optically pumped mixer was demonstrated and the potential for the system to be used for wireless transmission of data was also proved.

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