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New Applications for Microwave Photonics [Invited]

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***Abstract* – A photonic technique for generating high-purity millimetre-wave or terahertz signals based on heterodyne of two phase-locked optical sources is described. Technology requirements and potential applications are discussed.**

I. Introduction

Microwave photonics research has a long history [1] and has resulted in many diverse applications. In particular, wireless-over-fibre systems for distribution of cellular radio signals are now of significant commercial importance, with annual sales in the region of $250 m. With increasing demand for higher wireless transmission rates, but limited spectral bandwidth below 20 GHz, especially for unlicensed applications, attention is now turning to using photonic techniques to access the millimetre-wave band (30 – 300 GHz) and beyond (terahertz waves). Potential applications in the mm-wave band include high-speed fixed wireless access and home area networks, with wireless links at 10 Gb/s or higher already having been demonstrated at 60 GHz [2] and 120 GHz [3] over tens to hundreds of metres. At terahertz (THz) frequencies, there is interest in medical imaging, spectroscopy, and security screening [4].

In this paper, we describe techniques for generating very high spectral purity, low phase noise mm- or THz-waves by heterodyning phase-locked optical sources. We then consider how the approach can be extended to enable heterodyne detection, opening the way for communications or high-sensitivity spectroscopy to be carried out at terahertz carrier frequencies.

II. Photonic Signal Generation

A signal at mm-wave (or THz) frequency can be photonically generated by combining two optical waves with the appropriate frequency difference and detecting the beat signal using a photo-detector of sufficiently large bandwidth. To obtain a stable, low phase noise mm-wave carrier, the two optical signals must be phase locked to a common reference. The generation scheme we have developed is illustrated in Fig. 1. An optical frequency comb generator (OFCG) provides the reference, with optical phase lock loops (OPLLs) used to lock to two lines in the OFCG spectrum separated by the desired mm-wave frequency. The outputs of the OPLLs are combined onto a high-speed photo-detector, which drives an antenna.

We have investigated various comb generator implementations experimentally, including a re-circulating optical loop containing an RF-driven phase modulator [5] and an FM laser [6].

Conventional OPLLs constructed from discrete fibre-optic components have limited loop bandwidth, because of the large delay associated with the component fibre lengths, and therefore require narrow-linewidth lasers for good phase noise performance. One approach we have pursued to avoid this is to use an optical injection phase lock loop (OIPLL), which combines optical injection locking with low-bandwidth electronic feedback to produce a wide-bandwidth OPLL with improved tracking range compared to optical injection locking alone [7]. Alternatively, we are investigating monolithic and hybrid integration schemes for the OPLLs in order to reduce the contribution of the optical path to the loop delay to around 0.1 ns [8]. Integration of the major blocks of the photonic generator, as indicated in Fig. 1, would also be essential for the scheme to be considered feasible commercially.

III. UTC Photodiode

The photo-detector element of the photonic signal generator must have a significant response at the mm- or THz-wave frequency. For frequencies higher than 100 GHz this requires

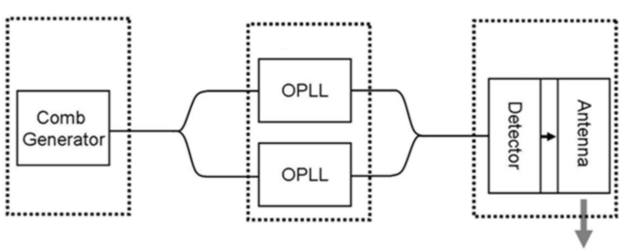

Fig. 1. Photonic millimetre- or THz-wave generator.

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a novel approach. The uni-travelling carrier (UTC) photodiode uses band-gap engineering to give high electron drift velocity and so achieve ultra-high bandwidth, while also reducing the carrier space-charge effect, giving higher saturation powers [9]. We are investigating a development of the UTC photodiode which uses travelling wave techniques [10]. A device showing a parasitic capacitance of around 25 fF gave a capacitance-limited -3 dB bandwidth of 127 GHz with a 50 Ω load. Power emitted from photonic THz generators using similar UTC photodiodes with various types of integrated antennas are shown in Fig. 2.

We are also investigating the UTC photodiode as an optoelectronic mixer. In this configuration, mm- or THz-wave signals received by an antenna are applied to the UTC terminals, while the optical beat signal from a photonic signal generator is applied to the optical input. Non-linear mixing between the received signal and the 'optical local oscillator' generates a signal at an intermediate frequency, which can be in the RF band, allowing easy amplification and processing. This heterodyne detection technique could be used as part of a mm-wave or THz-frequency communications system (Fig. 3), or for high-sensitivity spectroscopy or scanning applications.

In a proof-of-concept communication link demonstration, we used a commercial, multiplier-based source operating at 80.000 GHz, modulated with BPSK data at 500 kb/s and connected to a horn antenna with a gain of 20 dBi. The heterodyne receiver used a UTC optoelectronic mixer coupled to an identical horn antenna via a co-planar probe and driven by a photonic signal generator optical local oscillator at 79.995 GHz. The IF signal at 5 MHz was demodulated using a vector signal analyser. An example received eye diagram is shown in Fig. 4 for antenna separation of 5 cm. In this experiment, the transmission distance and data rate were limited mainly by the low mixer conversion gain of approximately -74 dB. Other UTCs operated at higher optical local oscillator powers have given conversion gains as high as -20 dB for down-conversion from 10 GHz, suggesting that considerably improvements should be possible.

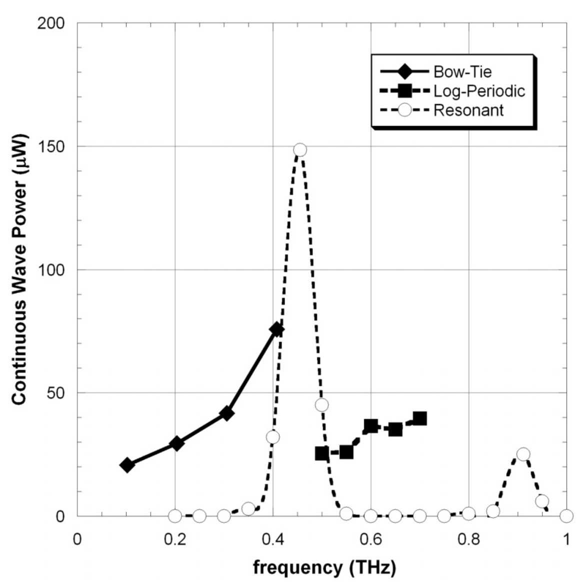

Fig. 2. Emission characteristics of photonic THz generators using UTC photodiodes integrated with various types of antennas.

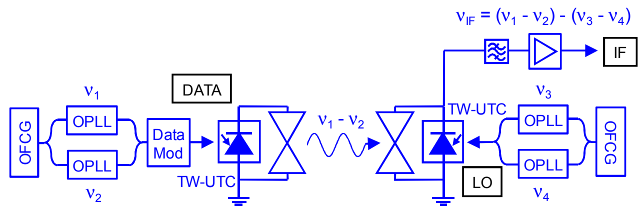

Fig. 3. THz communications system employing a UTC optoelectronic mixer for heterodyne detection.

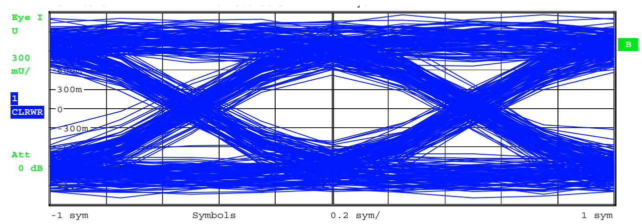

Fig. 4. Received 500 kb/s BPSK eye diagram from 80 GHz communication link using heterodyne receiver.

IV. Conclusions

A photonic technique for generating high-purity millimetre-wave or terahertz signals based on the heterodyne of two phase-locked optical sources has been described and the technology requirements discussed. High-speed photo-detectors, such as the uni-travelling carrier (UTC) photodiode, are key components in such a scheme. Results have been presented on UTC photodiodes both as sources of mm- and THz-waves and as down-converting mixers for heterodyne detection. It is anticipated that these approaches will enable new applications, such as high-capacity communications links and high-sensitivity spectroscopy.

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