10 to 110 GHz tunable opto-electronic frequency synthesis using optical frequency comb generator and uni-travelling-carrier photodiode

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Demonstration of tunable opto-electronic synthesis of millimetre-wave signals using an optical frequency comb generator is reported. Millimetre-wave signals from 10 to 110 GHz have been obtained by using a uni-travelling-carrier photodiode. Powers of up to 3 dBm at 60 GHz and small-signal 3 dB (electrical) bandwidths of > 85 GHz were obtained without the use of any electrical amplification.

Introduction: An optical frequency comb generator (OFCG) and a uni-travelling-carrier photodiode (UTC-PPD) is an excellent combination for mW-level tunable millimetre-wave opto-electronic frequency synthesis. The amplified fibre loop OFCG offers a wide comb span with adjustable, exact comb line spacing. Generation of more than 100 comb lines over a 1.8 THz bandwidth in the 1.55 µm band has been demonstrated [1, 2]. An optical injection locking scheme can be used to select two lines from the comb with exactly defined frequency spacing, enabling millimetre-wave signal generation with a high-speed photodiode [3].

In a UTC-PPD [4] the light is absorbed in the p-region and a potential barrier is incorporated so that only fast electrons act as carriers. As a result, its response is very fast and it responds with good linearity at optical powers of 100 mW order. Combining injection locked comb-line selection and UTC-PPD technologies, we report the first experiments on greater than one-decade span tunable, mW-level direct opto-electronic millimetre-wave generation. Unlike conventional millimetre-wave sources, the UTC-PPD can generate frequencies over a span limited only by its upper cut-off frequency. We obtained a 3 dBm output power at frequencies up to 60 GHz without the use of any electrical amplification. The small-signal 3 dB (electrical) frequency was measured to be > 85 GHz.

Experiment: The experimental configuration for the millimetre-wave generation is shown in Fig. 1a. It comprises a cascaded arrangement of an OFCG, two injection locked lasers as wavelength filters, an erbium-doped fibre amplifier (EDFA), and a UTC-PPD as the optical-to-millimetre-wave transducer. The OFCG emits a comb with arbitrary line spacing equal to the microwave reference frequency, f_{o_ref}, driving the phase modulator in the amplified fibre loop. A distributed feedback laser diode (DFB-LD) and a widely tunable sampled-grating distributed Bragg reflector laser diode (SG-DBR-LD) are injection locked so that each selects only one line. The SG-DBR-LD could be locked to any line in the OFCG output by adjusting its tuning section currents. The two laser outputs with frequency difference equal to the required millimetre-wave output are combined and amplified by the EDFA. The EDFA output is incident on the UTC-PPD and converted to millimetre-wave generation without the need for an expensive broadband millimetre-wave amplifier.

Fig. 1 Setup and typical spectra

- Experimental arrangement
- Millimetre-wave signal generation at 110 GHz

We used a tunable external cavity laser as a reference LD with wavelength 1557.3 nm. A reference signal from a microwave synthesizer, f_{o_ref}, was applied to the phase modulator in the OFCG. Most measurements were carried out with an f_{o_ref} of 10 GHz, except for the 75 GHz measurements where a 15 GHz microwave reference signal was used. The observed optical comb span was within a 30 dB power envelope was > 400 GHz or 3 nm. The SG-DBR-LD used provided a wide tuning range (> 60 nm) for ultra-broadband signal generation applications.

The UTC-PPD employed has an edge-coupling interface [5], which has a responsivity of 0.4 A/W and a 3 dB bandwidth of > 60 GHz at a bias voltage of ~4 V. A lensed-fibre was used to couple the OFCG output to the UTC-PPD, where the excess loss was ~3 dB. We used ground-signal-ground coplanar probes to collect the millimetre-wave power generated by the UTC-PPD chip. Although the probes have 0.83 dB loss at 60 GHz and 1.36 dB loss at 110 GHz, these are not corrected for in this Letter so that the results shown are conservative. The millimetre-wave power and phase noise were measured using a spectrum analyser for frequencies up to 50 GHz. Agilent 11974U and 11970W mixers were added for the measurements at 60 and 75–110 GHz, respectively.

Signals in the range 10 to 110 GHz were generated using this system. A typical synthesized spectrum is shown in Fig. 1b, where...
the millimetre-wave frequency is 110 GHz, the input light power 17 dBm, and the DC photo-current 10 nA. This shows that our experimental system can produce 110 GHz signal without electrical amplification. Fig. 2 shows the frequency response at the UTC-PD output for both small- and large-signal optical inputs. The mean input light powers were 1.8 and 17 dBm, respectively. The output power decreases gradually as the frequency increases. For the small-signal measurements, the 3 dB (electrical) bandwidth was estimated to be 85 GHz from interpolation. The arrows in Fig. 2 indicate the 3 dB frequency points. For the large-signal measurements, the response is flat within ±1.3 dB up to 60 GHz and the 3 dB bandwidth is 70 GHz.

We measured the RF output power dependence on the input light power, as shown in Fig. 3. The dependence is linear up to 15 dBm input for all the frequencies. Slight saturation was observed at 80 GHz between 16 and 17 dBm input. The highest power obtained at 60 GHz was 3 dBm, when the input power was 19 dBm, the power limit of our EDFA. At the high frequency limit of our measurements an output power of -9.8 dBm was observed at 110 GHz, for 17.8 dBm optical input to the UTC-PD. Because the UTC-PD does not show saturation for frequencies lower than 60 GHz, we could expect higher power to be obtainable with a higher-power EDFA. Phase noise performance is of great interest for wireless applications. Using this generation system, single sideband phase noise was measured over a 10-110 GHz range. The phase noise was measured as -74 to -28 dBc/Hz at 10 kHz offset from the carrier frequency over the entire frequency range.

**Fig. 2 RF output frequency responses**

\[ P_{\text{opt}} = 1.8 \text{dBm (small signal)} \]

\[ P_{\text{RF}} = 17 \text{dBm (large signal)} \]

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**Fig. 3 Output power dependence on input light power**

\[ 20 \text{GHz} \]

\[ 40 \text{GHz} \]

\[ 60 \text{GHz} \]

\[ 80 \text{GHz} \]

\[ 100 \text{GHz} \]

**Conclusion:** We have shown that the combination of an OFCG and UTC-PD produces a high-power, greater than one-decade span tunable millimetre-wave source. The maximum power obtained was 3 dBm at a carrier frequency of 60 GHz, which was limited by the EDFA output power. For a frequency range of 10-110 GHz, the minimum output power was >-9.8 dBm measured at the highest frequency of 110 GHz. This synthesis approach can play an important role in millimetre-wave signal generation for fibre-fed wireless applications since the upper frequency limit is set mainly by the photodiode bandwidth and the modulated optical signals can be transmitted over long distances through optical fibre prior to detection.

**References**


