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Microwave Photonic RF Comb Generator up to 140 GHz

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Abstract *A microwave photonic RF comb generator for generation of stable radio frequency combs is presented. It combines an fs-pulse laser and a broadband photodetector module. The subsystem generates a pulse with a FWHM of 5.8 ps and generates an RF comb up to 140 GHz. ©2022 The Author(s)*

Introduction

Microwave photonics is a promising field with the ability to overcome various drawbacks of purely electronic microwave generation systems [1, 2]. Wide bandwidth, low phase noise, highly stable microwave signal generation and low loss optical distribution are major advantages compared to purely electronic microwave generation [1-3]. Therefore, microwave photonics is a key enabler for research areas as next-generation RF sources, 6G communication systems with sub-THz frequencies in the F-band [4, 5], radio astronomy, and broadband, high-resolution microwave radars [3]. Especially for measurement systems, it is beneficial to have a single RF source covering a wide frequency range from DC to above 100 GHz, ideally without the requirement for reconfiguration.

RF signals are generated by heterodyning two spectrally different optical sources within a photodetector [3]. To increase the purity of the down-converted RF photodetector signal, phase-locking the optical sources to each other is mandatory. Therefore, optical frequency combs with extremely low phase noise like fs-pulse lasers are promising candidates [1, 2, 6]. The optical frequency comb generates harmonics of the fs-pulse laser repetition rate [1]. The effect is similar to a frequency down conversion process. Hence, the phase noise is reduced by the frequency division factor from the optics domain to the microwave range [1].

Since the optical comb includes many equally spaced spectral lines, the generated RF comb consists of frequencies spaced with a spectral distance of the repetition rate, ranging up to the cut-off of the photodetector [1], being often a limitation for the frequency of optical generated RF signals.

To exhaust these limitations, we demonstrate a turnkey microwave photonic RF comb generator for broadband generation of RF ranging from DC up to 140 GHz with edge-cutting components like a compact low phase noise frequency comb fs-pulse laser module and a broadband 145 GHz photodetector module.

Setup of the Photonic RF Comb Generator

The microwave photonic RF comb generator, shown in Fig. 1, consists of two major components: a fs-pulse laser module and a broadband photodetector module. The fs-pulse

Fig. 1: Experimental setup of the photonic RF comb generator with 145 GHz photodetector module, illuminated by a commercial fs-pulse laser through a VOA and a polarization controller

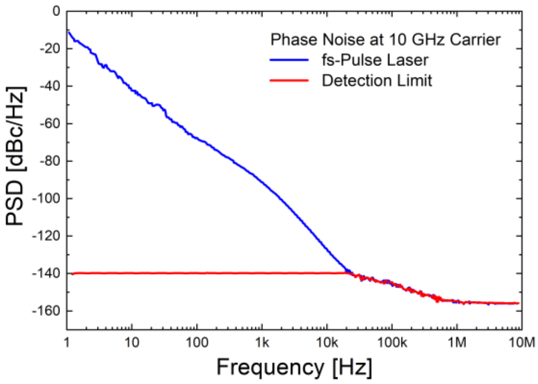

Fig. 2: Phase noise of the fs-pulse laser measured on 10 GHz equivalent carrier

laser has ultra-low phase noise and a 1 GHz repetition rate [6]. As shown in Fig. 2, the laser has a phase noise of below -60 dBc/Hz at a 100 Hz frequency offset and around -130 dBc/Hz at a 10 kHz frequency offset and, while reaching below -150 dBc/Hz above 1 MHz frequency offset. Fig. 3 shows the optically generated pulse of the fs-laser measured with an autocorrelator. The optical pulse has a pulse width of 508 fs. Hence, the laser will not limit the bandwidth of the photodetector module.

The second component is a broadband photodetector module [7] with an estimated 3 dB-bandwidth of 145 GHz and a responsivity of 0.4 A/W at 1550 nm. It includes a 0.8 mm-RF connector as an RF-interface in order to support the broadband behaviour (Fig. 4).

By combining these components into an optical subsystem, an electrical frequency comb with its spectral line spacing equal to the repetition rate of the laser source is generated.

Additionally, we use a variable optical attenuator (VOA) to control the optical power, injected into the photodetector. In order to prevent unwanted saturation effects, the VOA controls the fs-pulse laser output power without changing the operation point of the fs-pulse laser.

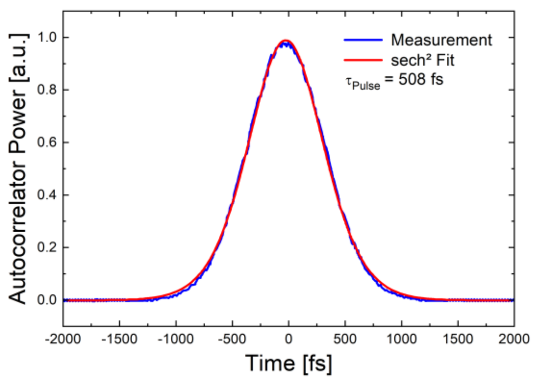

Fig. 3: Autocorrelation trace of the optical output of the fs-pulse laser on the output fiber. The fit corresponds to a pulse FWHM of 508 fs.

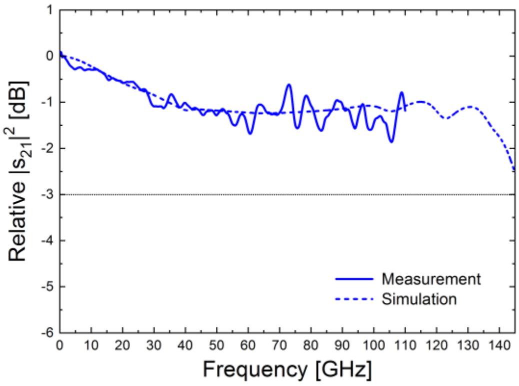

Fig. 4: RF response of the photodetector module (measured up to 110 GHz and simulated up to 145 GHz)

In addition, for maximizing the RF output power a polarization controller aligns the polarization orientation into the photodetector to TE.

Measurement Results

The implemented photonic RF comb generator is characterized with various measurement techniques to evaluate experimentally the potential performance for RF signal generation.

With a 100 GHz oscilloscope the generated electrical pulses of the photonic RF comb generator are examined. Fig. 5 shows the pulse measured for different average photocurrents of the photodetector, being controlled by the VOA. At higher average photocurrents, the pulse shape widens due to photodetector saturation effects, while at lower optical powers, the pulse width is approx. 5.8 ps, mainly limited by the bandwidth of oscilloscope.

Fig. 6 shows the measurement results of the generated RF comb by using a 110 GHz electrical spectrum analyser (ESA). The measurement is applied at the same optical power settings as the time domain measurement. For clarity, the upper envelopes of the obtained spectra for higher power levels are only

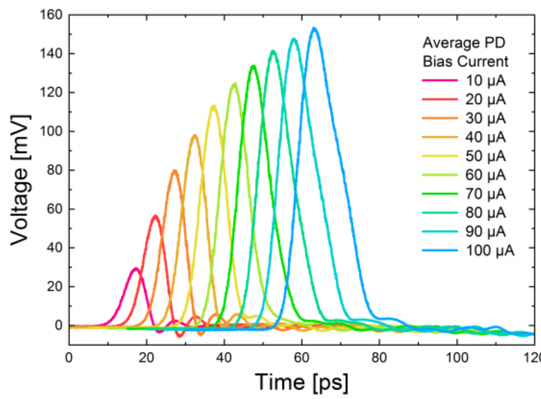

Fig. 5: Measured RF pulses of the photonic RF comb generator under variation of the VOA attenuation, indicated by the average PD bias current

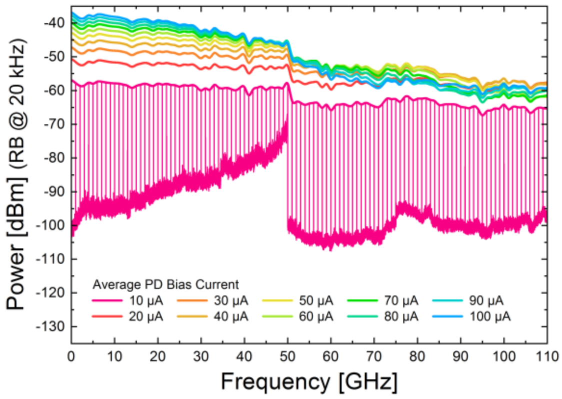

Fig. 6: Generated frequency combs with 1 GHz spacing. Note that for clarity only the envelope is shown for 20 uA Average PD Bias and above

presented. As a reference, the whole spectrum is shown for lowest average bias current setting of 10 µA. The resolution bandwidth is set to 20 kHz and the video bandwidth is set to 20 Hz. We believe that the dip at 50 GHz is a measurement artefact due to an internal ESA operation mode switching. The spectrum behaves as expected since it shows a flat RF comb generation over the entire spectrum. For higher optical powers, the photodetector starts to saturate, resulting in a power decrease for larger frequency components. Due to the pulsed input signal, the frequency response differs from Fig. 4 and corresponds to the previous discussed pulse behaviour.

To examine the behaviour of the photonic RF comb generator for even higher frequencies we use a 145 GHz vector network analyser (VNA). Because of the narrow linewidth of the generated frequencies and the frequency down conversion processes within the VNA, the measurement the measurement could not be extended over a spectral range of 500 MHz. Therefore, we exemplary measured the spectral line at 140 GHz, which underlines the ability to generate an

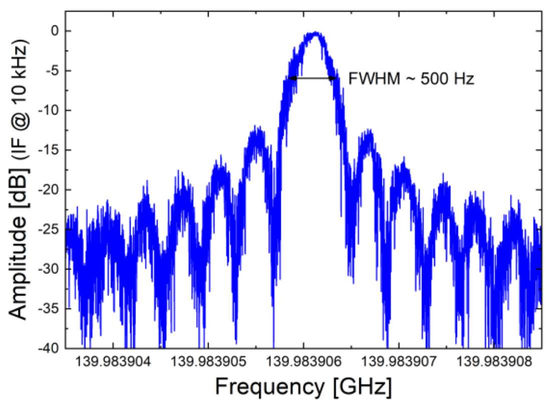

Fig. 7: Generated spectral RF comb line at 140 GHz using a 5 kHz span

RF comb from 1 GHz to 140 GHz (Fig. 7). The measured FWHM bandwidth of the generated RF line is ~ 500 Hz, which lies within the measurement accuracy of the measurement system.

Conclusion & Outlook

We demonstrated a photonic RF comb generator up to 140 GHz with the capability for stable RF oscillator applications, when extracting single spectral carriers. In the time-domain, the photonic RF comb generator generates electrical pulse with minimum FWHM of 5.8 ps and a repetition rate of 1 GHz. In the frequency domain the generated RF comb shows a flat response over the entire spectrum up to 110 GHz and an exemplary RF signal at 140 GHz, representative for the RF comb generation from 1 GHz up to 140 GHz. Saturation effects were observed for higher optical power levels into the photodetector module.

In order to avoid the saturation of the photodetector and therefore the intended attenuation of the fs-pulse laser power by the VOA, either a better dispersion management between the fs-pulse laser and the photodetector has to be implemented or the fs-pulse laser with higher repetition rate and broader pulses can be used [8], up to 2.5 GHz and more in the near future. The presented microwave photonic RF comb generator has the potential for broadband, stable and low phase noise RF frequency synthesis covering a large number of frequency bands without the need for reconfiguration.

Even if the presented microwave photonic RF comb generator is an easy-to-use turnkey solution, the reduction of the size with even more compact fs-pulse lasers is being on the roadmap for next generation ultra-high photonic RF comb and signal generators.

Acknowledgement

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