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Waveguide Based Photonic-Transmitter-Mixer at W-band for Photonic Generation of Few-cycle Millimeter-Wave Pulses

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1. Introduction

The photonic generation of ultrashort electrical pulses in either free space or transmission lines has been widely investigated over the past forty years. However, the generated sub-THz power in these techniques is usually too small and hinders further improvement in the system performance. The most straightforward solution to this low-power issue is to photonically generate the short electrical transients in a sub-MMW waveguide, where the ensuing signal amplification and processing are feasible through the use of commercially available waveguide based active/passive MMW components. Despite the advantages, a waveguide is effectively a passive band-pass filter. Such band-pass nature causes detrimental loss, waveform distortion, ringing oscillation and pulse broadening when a short photo-generated electrical Gaussian pulse (covering frequency range from nearly DC to sub-THz) propagates down a waveguide.

In this paper, we demonstrate a novel scheme for photonic generation of few-cycle MMW short pulses at the W-band using a WR-10 waveguide based photonic-transmitter-mixer (PTM) [1,2] with ultra-fast modulation characteristic. The proposed technique is beneficial in eliminating the use of an external modulator integrated with a high-power RF amplifier, canceling the ringing oscillation in the tail of MMW pulse, and offering the narrowest pulse-width among all the discussed techniques in this paper.

2. Bias Modulation Measurement Setups and Results

In order to further overcome the limitations in pulse-width and the peak amplitude, we have proposed another solution, which is shown in Figure 1 (a). In this setup, the continuous optical MMW signal at 93 GHz is simply generated by the hetero-dyne beating technique. In order to get the short-pulse waveform, two different schemes (A and B) have been adopted. In scheme A, we use a $LiNbO_3$ based external E-O modulator (MOD) to mix the continuous 93 GHz sinusoidal signal with the short electrical pulse (square wave) with a 25 ps pulse-width, which is generated by the pulse pattern generator. We can thus expect that the output from the E-O MOD is an optical pulse (envelope) with a pulse-width at around 25 ps and a few cycles of 93 GHz carrier inside. An additional high-power RF amplifier is necessary in this scheme to amplify the input 25 ps electrical pulse to the output level with peak amplitude at ~ 5V for driving the E-O MOD.

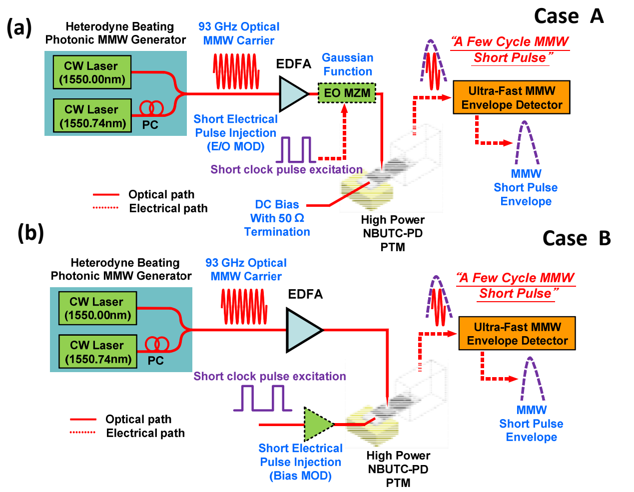

Figure 1. The measurement setup for the demonstrated MMW short-pulse generation system. E-O MZM: electro-optic Mach-Zehnder modulator. MOD: modulation.

Another approach (scheme B) is to use the ultra-fast modulation characteristic [1,2] of our PTM to generate the MMW pulse. As shown in Figure 1, in the receiver-end, we use a very-fast MMW power detector, which has around 37 GHz video bandwidth [5], to directly detect the envelope of emitted MMW pulse through the WR-10 waveguide. The injected electrical pulse train into IF port of PTM or EO-MOD has a pulse-width fixed at 25 ps and the same 400 ps repetition time for both cases. By pre-biasing our PTM under around -1V DC voltage with around 1V peak-to-peak IF driving voltage, we can get the largest amplitude of generated MMW pulse. Here, we assume that our fast MMW detector in our receiver has a Gaussian-shape impulse response with a 28 ps FWHM, which corresponds to its 37 GHz video bandwidth [2]. Figures 2 and 3 show the measured waveforms under the different output photocurrent (or charge per pulse) for schemes A and B with narrowest pulse-widths, respectively. The ringing oscillation in the tail of measured impulse responses under optical pulse excitation (scheme A), can be completely eliminated by use of bias modulation. This is an important issue for radar applications due to the fact that such ringing oscillation might mix with the reflected waves and have serious influence on the echo signals from objects under measurement. The superior performance of the bias modulation technique to optical pulse excitation may be attributed to the fact that the NBUTC-PD PTM provides a sharp transfer function [3] and it can further sharpen the generated MMW pulse.

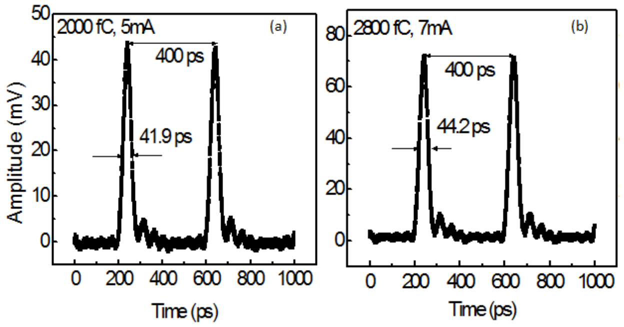

Figure 2. Fixed reverse bias voltage (~ -4V) and different output charges per pulse for (a) 2000 fC (5mA averaged current), (b) 2800 fC (7 mA averaged current).

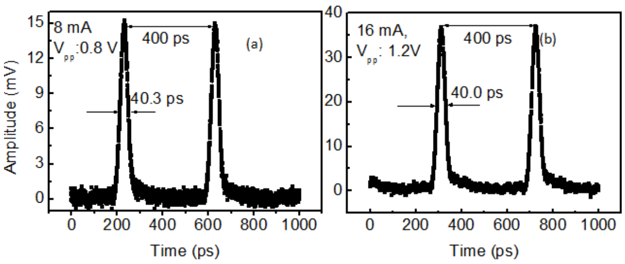

Figure 3. Fixed reverse bias voltage (-1V) and different output photocurrents of (a) 8 mA, (b) 16 mA. The IF driving voltage (V_{pp}) for (a) and (b) has been optimized for narrowest FWHM and highest peak amplitude.

To manipulate the generated MMW pulse-width with some proper phase and amplitude coding plays important role to further enhance the resolution of radar image [4]. By use of our proposed bias modulation technique (scheme B), the generated MMW pulse-width can be easily controlled by the injected electrical pulse-width to the IF port of our PTM. Figure 4 (a) shows the measured waveform of impulse responses by use of scheme B (bias modulation) with different electrical pulse-width injected to the IF port. Figure 4 (b) shows the corresponding pulse-width of measured MMW impulse response versus those of injected pulses to the IF port.

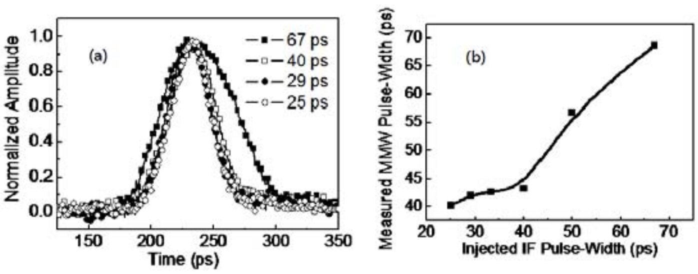

Figure 4. (a) The measured envelope waveforms (without de-embedding the receiver time resolution) of the MMW pulses obtained using scheme B with different electrical pulse-widths injected to the IF port. (b) The corresponding FWHMs of the measured MMW envelope versus injected pulse-width.

As can be seen, when the injected IF pulse-width is reduce from 70 to 40 ps, the generated MMW pulse-width decreases significantly. On the other hand, when the injected IF pulse-width is narrower than 40 ps, the reduction in generated MMW pulse-width becomes not significant. This phenomenon is mainly due to that the generated MMW pulse-width (impulse response) is eventually limited by the modulation bandwidth of our IF port (25 GHz) and the video bandwidth of our envelope detector (~37 GHz) [2]. The decrease in generated MMW pulse-width thus become non-significant by further reducing the injected IF pulse-width (< 40 ps).

3. Conclusion

In conclusion, we have demonstrated a novel photonic MMW short pulse generation technique using a MMW waveguide based PTM. In our new approaches, the external high-speed E-O MOD or the IF bias modulation port of our PTM is used to mix the continuous optical MMW signal at W-band with the envelope of short electrical pulse train. As compared to using the high-speed (40 Gbit/sec) E-O MOD under pulse-mode operation, the bias modulation technique can provide the narrower MMW pulse-width and kill the ringing oscillation in the tail of generated short MMW pulse due to the ultra-fast bias modulation characteristic and the sharp transfer function of our PTM.

References

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