# High spectral purity chip-scale tunable THz radiation source

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**Abstract:** Broadly tunable THz radiation is generated at room temperature after injecting the tunable optical parametric oscillation emitted from a microresonator into a bias-free photomixer. The radiated THz wave features Hz-level linewidth and frequency stability. 
**OCIS codes:** (140.3945) Microcavities; (190.3270) Kerr effect; (190.7110) ultrafast nonlinear optics

## 1. Introduction

High-Q nonlinear integrated resonators [1,2] have emerged as a new platform over the past decade, and have revolutionized many fields such as dual-comb spectroscopy, chip-scale optical clock, quantum-entangled optical sources, and microwave photonics. The nonlinear resonators dominated by third order Kerr nonlinearities significantly enhance nonlinear interactions and achieve high conversion efficiency in phenomena such as degenerate four-wave mixing, where two pump photons are parametrically converted to signal-idler satisfying both frequency and phase matching conditions [3,4]. The conversion efficiency is dependent on the frequency matching among the interacting resonant modes. Therefore, it is highly desirable to obtain tunable frequency matching for broadband parametric oscillation generation. Here, we generate frequency-tunable hyperparametric oscillations to efficiently transfer pump light into new frequencies over a broad optical bandwidth. The frequency of the parametric oscillations can be tuned by changing the pump-resonance detuning with excellent frequency tuning repeatability and linearity along the forward and backward pump frequency tuning directions. The frequency change of the parametric oscillation is 200 times of the pump frequency change. The tunable optical parametric oscillations are then injected into a bias-free photomixer operating at room temperature. Broadly tunable THz wave from 0.3 THz to 0.75 THz is generated without optical spectral shaping. Then, THz frequency comb is generated by optimizing the pump power to excite the sub-comb lines around the main parametric sideband. By feedback controlling the intracavity power of the microresonator, THz radiation with a Hz-level linewidth is measured, limited by the frequency resolution of the available instrument. The flexible frequency matching condition allows us to demonstrate, for the first time, broadly tunable chip scale THz generation with high spectral purity through Kerr microresonators without optical spectral shaping. The developed THz radiation source can be used for frequency-domain THz spectroscopy.

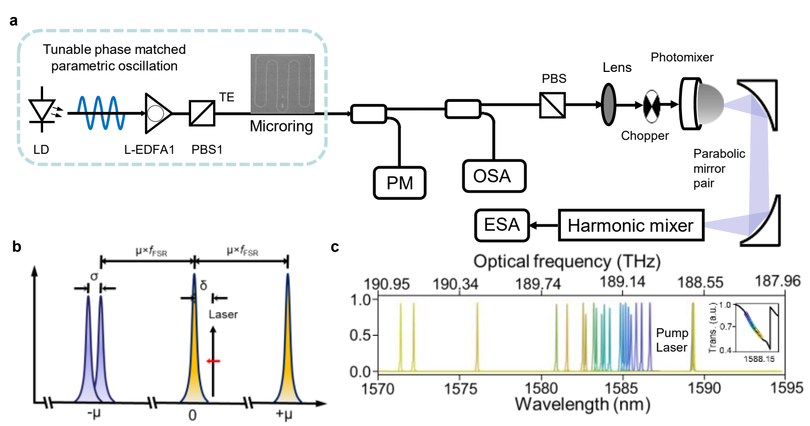


Fig. 1: Tunable phase-locked parametric oscillation. (a) Experimental setup for the tunable phase-locked sideband generation and THz generation/detection, LD: laser diode, L-EDFA: L-band Erbium-doped fiber amplifier, PBS: polarization beam splitter, TE: transverse electric, PM: power meter, OSA: optical spectrum analyzer, ESA: electrical spectrum analyzer; (b) Mode-splitting assisted tunable phase matching mechanism; (c) Tunable phase-locked optical sideband generation by changing the pump-resonance phase detuning, inset shows the traditional thermal triangle indicating the corresponding effective detuning.

## 2. Results and Discussion

Figure1a illustrates the experimental setup we used for tunable phase-locked optical parametric sideband generation as well as THz generation and detection. Figure1a includes the SEM micrograph of the microcavity. The width of the semi-circle waveguide is 1μm supporting the fundamental mode and working as a mode filter [5]. The straight waveguide has a tapered width from 1 μm to 2.5 μm, which will enable dispersion tailoring. The total cavity length is 8.1 mm corresponding to an FSR of 20 GHz. Figure 1b shows mode-splitting assisted tunable phase matching mechanism. Broadly tunable phase-locked optical sideband is generated by changing the pump-resonance phase detuning as shown in Figure 1c and inset shows the traditional thermal triangle, indicating the corresponding effective detuning. Figure 2a shows the generated THz wave spectra after down-conversion to the radio frequency (RF) domain around 1 GHz. The measured THz frequency range is limited by the harmonic mixer operating bandwidth. The down-converted RF tones show a signal to noise ratio (SNR) of more than 40 dB and 3-dB linewidth of around 10 kHz measured in 50 ms. This linewidth is determined by the intracavity power fluctuations and pump laser linewidth. By optimizing the pump power, the tunable THz frequency comb with an FSR of 20 GHz is also generated by exciting sub-comb lines around the parametric sideband. By actively feedback locking the intracavity power, the radiated THz wave can obtain a Hz-level linewidth and frequency stability. Figure 3a shows the experimental setup used for the active feedback control. Figure 3b shows the frequency stability of the radiated THz signal showing a 0.64 Hz RMS frequency variation over two thousand seconds. Figure 3c shows the corresponding instantaneous 3-dB linewidth, which indicates the Hz-level linewidth over a 100 Hz frequency span limited by the instrument frequency resolution.

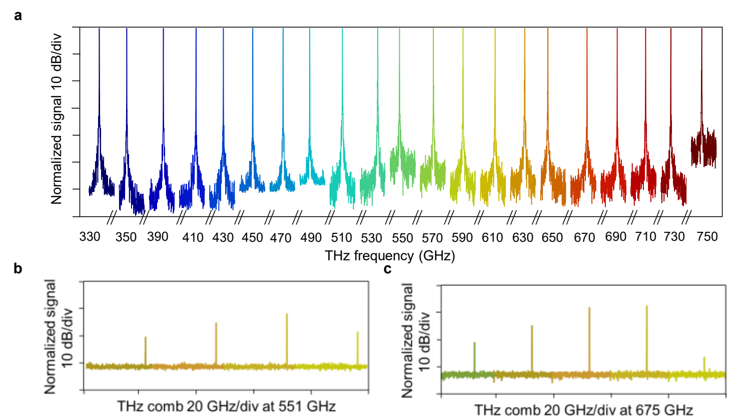


Fig. 2: Tunable single tone THz radiation and THz comb generation without optical spectral shaping. (a) Tunable single-tone THz radiation from 330 to 750 GHz with more than a 40 dB single-noise ratio achieved by continuously sweep two adjacent resonances, (b) THz frequency comb with a center frequency of 551 GHz and FSR of 20 GHz, (c) THz frequency comb at 675 GHz.

## 3. Conclusion

In conclusion, broadly tunable THz wave generation from 0.3 THz to 0.75 THz is demonstrated without optical spectral shaping. By using active intracavity power stabilization, the radiated THz wave shows a Hz-level linewidth and frequency stability over two thousand seconds. The demonstrated THz source can be used for wireless communication and spectroscopy applications.

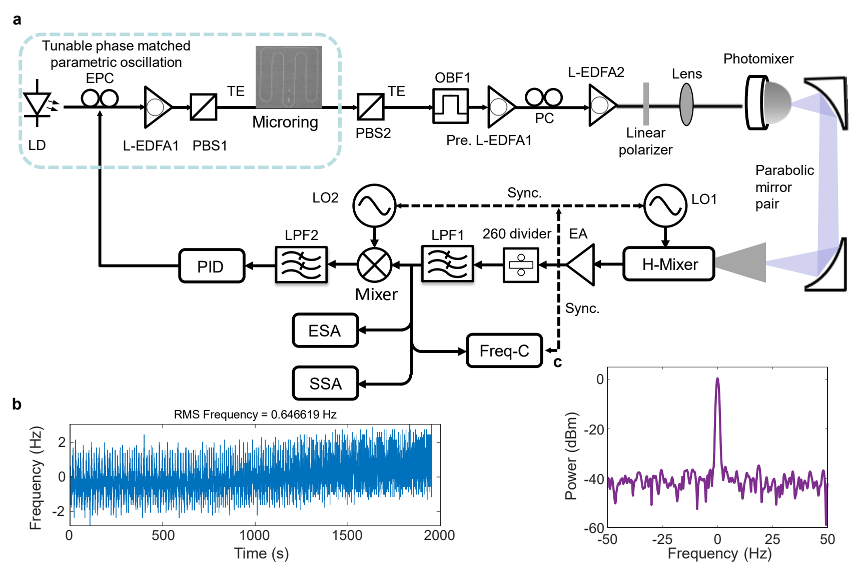


Fig. 3: Active feedback control of the frequency stability of the radiated THz signal. (a) Experimental setup, EPC: electrical controlled polarization controller, OBF: optical bandpass filter, LO: local oscillator, EA: electrical amplifier, LPF: low pass filter, Freq-C: frequency counter, SSA, signal source analyzer; (b) Frequency stability; (c) linewidth of the down-converted signal.

## 4. References

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