Supplimentary material for
Intense, wideband optical waveform generation by self-balanced amplification of fiber electro-optical sideband modulation

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I. ASE SUPPRESSION AND THE OPTICAL FILTER

We use a home-made wavelength-meter [1] to characterize the ASE background for both the TSA_1 and TSA_2 outputs. For this purpose, the laser power spectrum is measured under three operation modes: by $E_{\rm f1,out}$ seeding under full modulation ($A(t) = 1$ in Eq. (2) in maintext) to maximize the $-1^{\rm st}$ order), by $E_{\rm f1,out}$ seeding without modulation (with full power in $0^{\rm th}$ order), and with TSA free-running (no seeding). We expose the camera twice in each measurement to separately retrieve the spectrum density of the coherent output and the ASE background. The background fluorescence is measured with a 100 ms exposure time, while the central coherent spectrum following the injected laser is measured with a 7 μs exposure time. The two spectrum data are then combined in Fig. 1b after being relatively normalized by the ratio of the exposure time. Here the $\sim$ 3 GHz frequency resolution of the spectrometer is beyond the 4 MHz laser linewidth in this work, as verified by independent measurements. We normalize the spectrum density according to the laser linewidth to obtain the peak spectrum density relative to the ASE background. The spectrum density of the coherent output is $\sim$ 75 dB above the ASE background at the seeding frequency which composes $\xi_1 = 90\%$ of the $P_1 = 140$ mW total output power. Compared with TSA_1 in the free-running mode, the $E_{\rm f1,out}$ seeding leads to $\sim$ 10 dB suppression of ASE background, similar to Ref. [2]. As discussed in Sec. IIB, with the $\rm Filter_1$ bandwidth $\Delta\omega_1 \approx \omega_{\rm c}$, the $E_{\rm f1,out}$ seeding maintains the average seeding power $P_{\rm f1} \approx 0.6$ mW during fEOM modulation, leading to a nearly identical level of ASE suppression regardless of the $E_{\rm f1,out}$ modulation strength. Similar ASE suppression is also obtained for TSA_2, with the coherent output composing $\xi_2 = 84\%$ of the 720 mW total power and is $\sim$ 70 dB beyond the ASE background in spectral density.

A. SPM suppression

We verify the picture of SPM suppression at large carrier frequency $\omega_{\rm c}$ with an independent measurement. In particular, we replace the fEOM output (see Fig. 1 in the maintext) with a seeding laser that contains two frequency components with nearly equal amplitudes and a tunable difference δf. The total 1 mW power is similar to the fEOM output. As

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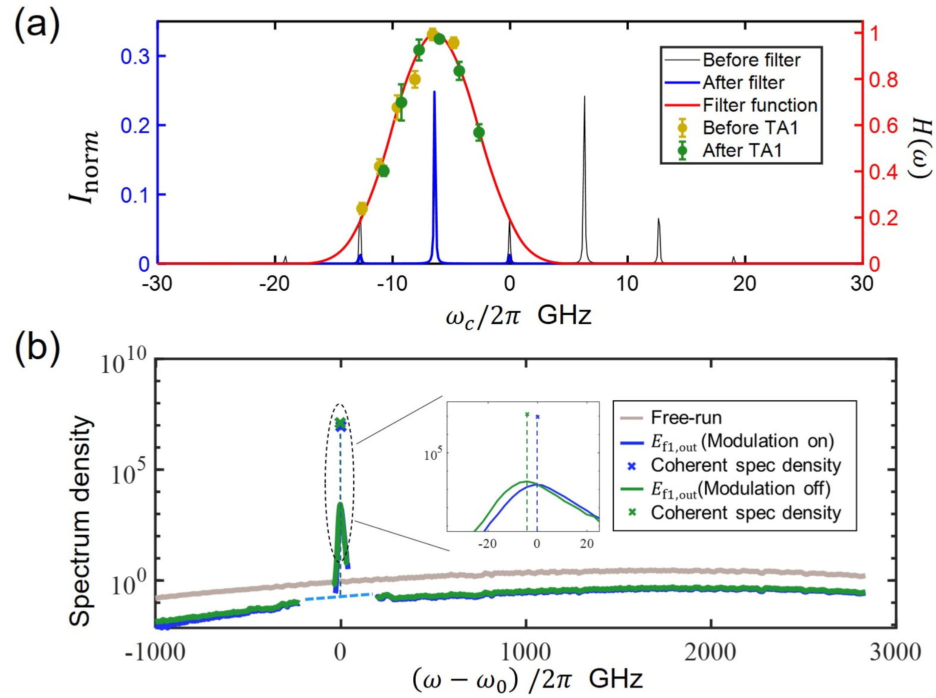

FIG. 1. (a) Bandwidth measurement for the $n_0 = -1$ order output when the microwave carrier frequency ω_{c} is sampled between $4-14$ GHz. The data points are for $n_0 = -1$ order outputs before and after TSA_1 amplification, identified by a F-P spectrometer and normalized by the peak values. The EOM phase modulation depth $\theta_0 \approx 1.8$ is optimized for the $n_0 = -1$ order. The black and blue lines are $E_{\mathrm{fEOM,out}}$ and $E_{\mathrm{f1,out}}$ according to a numerical model of the grating-based optical filtering. The red curve is the Filter_1 function $H(\omega)$. (b) The spectrum of TSA_1 output measured with a grating spectrometer. The 'X' markers estimate the peak spectrum density according to the linewidth of the coherently amplified laser output.

schematically illustrated in Fig. 2a, additional sidebands are generated during the optical amplification through the SPM mechanism. An F-P spectrometer analyzes the power distribution of the sidebands. The SPM efficiency is characterized by the power of the additional sidebands normalized by the total power as $\mathcal{E} = P_{\mathrm{nonli}}/P_{\mathrm{tot}}$. We measure $\mathcal{E}$ as a function of δf. The results in Fig 2 demonstrate a $1/\delta f^2$-scaling of suppressed SPM at large δf , agreeing with similar previous measurements [3]. Therefore, for the quasi-continuous seeding by $E_{\mathrm{f1,out}}$, the frequency separation of $\delta f = \omega_{\mathrm{c}}/2\pi = 6.4$ GHz is large enough that the optical power distributed into additional sidebands are limited to $\mathcal{E} \approx 2 \sim 4\%$ during the optical amplification.

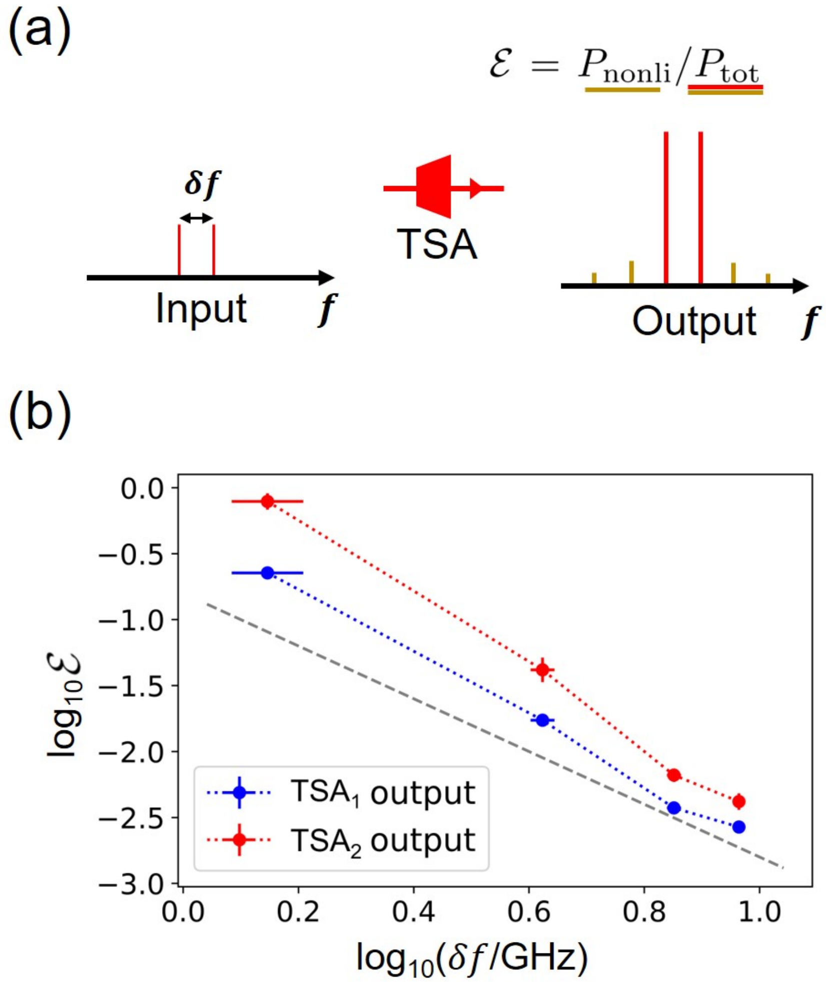

FIG. 2. Investigation of SPM as a function of modulation frequency δf. (a): TSA is seeded with dual-frequency input with frequency difference δf. The output is analyzed by a Fabry-Perot spectrometer. The nonlinear side band power ratio $\mathcal{E}$ is recorded. (b): Sideband ratio $\mathcal{E}$ vs frequency difference δf. The error bars reflect the uncertainty of δf and $\mathcal{E}$ measurements. The dashed line gives the $1/\delta f^2$ scaling.

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