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Advances in ultrafast photonic spectrograms towards sub-THz bandwidths

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Time-frequency representations, such as spectrograms, are amongst the most complete descriptions of temporal signals. These time-resolved spectral representations of signals are critical for ranging [1], cognitive communications [2], and radio-astronomy [3]. Previous technology fails to provide analysis bandwidths of 10s of GHz, with time resolutions below a nanosecond, in a real-time and gapless fashion. In this abstract we summarize our recent work in the direction of extending the operational bandwidths of real-time photonics spectrograms to the sub-THz range, with sub-nanosecond time resolutions.

The Time Lens Spectrogram (TLS) consists of two linear phase transformations in the optical domain resulting in consecutive and gapless Fourier transforms of short segments of the input signal mapped into the temporal domain [4]. A consecutive array of time lenses (each with a temporal phase modulation $\varphi(t) = C_L t^2/2$, where C_L is the strength of the time lens over time t) is applied first, followed by a spectral phase modulation $\phi(\omega) = \ddot{\phi}\omega^2/2$, where $\ddot{\phi}$ is the second order dispersion parameter over angular frequency ω. Both manipulations are related by $C_L\ddot{\phi} = 1$. The other key design condition is that the full signal bandwidth must be less than the time-lens bandwidth $|C_L|T_L$ to map the spectrogram over a duration shorter than the aperture of each of the time lenses. A diagram of the experimental setup is shown in Fig. 1(a-c). The signal under test (SUT) consists of a series of frequency hops in the microwave domain, which are generated by a 120 GS/s arbitrary waveform generator (AWG) and modulated onto an optical carrier continuous wave laser (CW) at 1550 nm by an intensity modulator (IM). We program the consecutive quadratic functions in (1) using the same AWG to drive a 40 GHz electro-optic phase modulator (PM). The spectral phase modulation of (2) is implemented using a linearly chirped fiber Bragg grating (CFBG) with 1,965 ps/nm of dispersion. The time mapped spectrogram is recovered by a 50 GHz photodiode (PD) and 28 GHz real-time oscilloscope (RTO), Fig. 1c. The electronic signal from the AWG is shown in Fig. 1d. The spectrum measured with an optical spectrum analyzer is shown in Fig. 1e. The spectrogram reshaped into 2 dimensions, scaled to make the standard deviation of the noise equal to 1, with the intensity expressed in dB, is shown in Fig. 1f. Our spectrogram experimentally achieves a full analysis bandwidth of ≈ 40 GHz, a Fourier transform rate of 1.56 GFT/s, and a resulting time and frequency resolution of 640 ps and 1.56 GHz, respectively.

Using our real-time photonics spectrogram, we can track broadband frequency events over ultrashort durations with ease. Our system outperforms all other reported real-time, gapless spectral analysis methods to date, electronic and photonic, in terms of speed and bandwidth, allowing for novel applications of this powerful tool.

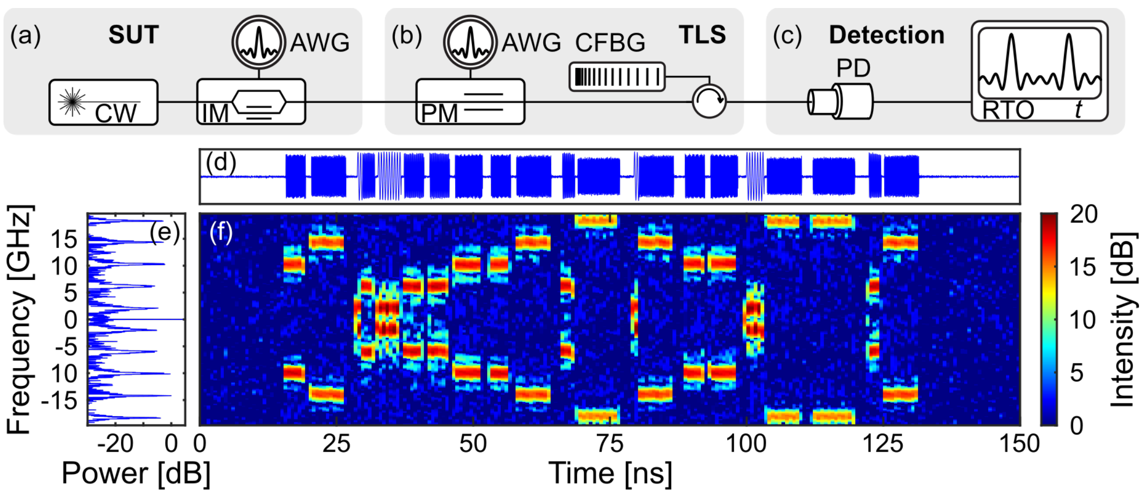

Figure 1. (a-c) Experimental setup. (d-f) Using a time-lens spectrogram with ~40 GHz analysis bandwidth and 640 ps time resolution, we recover the time-frequency information of a frequency hopping communication signal.

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