National Aeronautics and Space Administration

Demonstration of Heterodyned Arrayed Waveguide Grating Photonic Spectrographs

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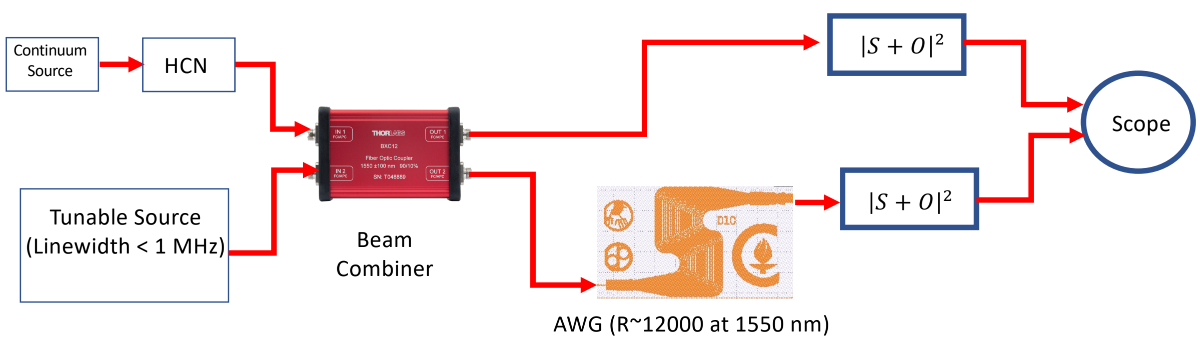
Objective Develop a testbed for heterodyne experiments to demonstrate heterodyning a single Arrayed Waveguide Grating (AWG) output channel (with a resolving power R~10,000 at 1550 nm), with a tunable narrow band "line" source (< 1MHz, between 1460-1620 nm) to achieve a factor of 10 increase in spectral resolution.

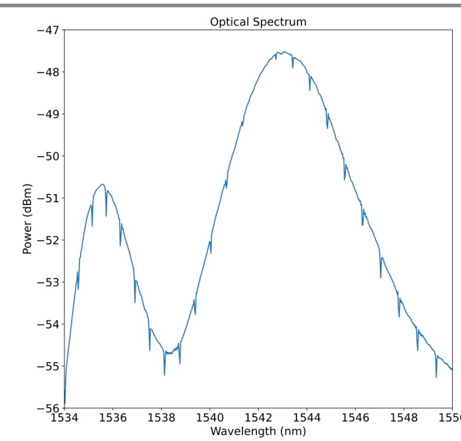
Background The development for single-mode, high-resolution spectrographs is an enabling technology for space-based Extreme Precision Radial Velocity (EPRV) missions for Earth-like exoplanet detection. EPRV measurements require Near-Infrared (NIR) (together with optical) spectroscopy with resolving powers of R>150,000, with Spectral Response Functions (SRFs) calibrated to cm/sec precision. Photonic spectrographs, with their compact size of tens of millimeters, can provide important gains over bulk single-mode spectrographs in SRF stability in dynamic thermal and mechanical environments. Photonic Arrayed Waveguide Grating (AWG) spectrographs, currently in development at JPL/Caltech, are now achieving R~10,000, and with refined designs should achieve throughputs comparable to bulk-optics spectrographs. Pushing AWG technology to R>100,000 represents a challenge which increases the complexity of the AWG IPS designs (through cascading multiple AWGs, with thousands of output waveguide channels). Here we develop a hybrid approach to high-resolution photonic spectrographs with parallel channel frequency comb heterodyning of the AWG output channels, providing one or two orders of magnitude increase in spectral resolution.

Approach and Results Our approach integrates heterodyne spectroscopy with an initial stage of AWG dispersion into channels of a bandwidth matched to our photodetector speeds of 20-40 GHz. Without the AWG, mixing frequency comb lines with broadband light on a detector would generate a heterodyne signal with several sampling "sinc" bands contributing to an RF "beat frequency", preventing unique spectral demultiplexing. We setup the testbed as shown in figure 1, with the tunable line source, HCN gas cell, AWG chip, and photodetector + Tektronix oscilloscope backend. The AWG output channel containing the local oscillator is brought to the photodiode where the light is "squared", generating the heterodyne beat frequency signal. The photodiode output is then electronically Fourier transformed with the oscilloscope to achieve a factor of 10 or more in spectral resolving power in the selected AWG output band. In figure 2, we show a measured spectrum of our Erbium-Doped Fiber Amplifier (EDFA) source after passing through the HCN cell.

Significance/Benefits to JPL and NASA Developing high-resolution (R>150,000) single-mode spectrographs are an enabling technology for extreme precision radial velocity measurements for the detection of Earth-like exoplanets. Single-mode spectrographs decouple the stability of the spectral response functions from the telescope aperture. A photonic spectrograph offers potentially even spectral response stability due to the small size of arrayed waveguide grating photonic spectrographs (with millimeter dimensions), leading to robustness against thermal and mechanical variations. However, pushing the resolving power of AWG photonic spectrographs leads to cascaded AWG designs with additional throughput loss. The alternative explored here is to heterodyne the AWG channels of a bandwidth matched to the photodiode sampling speed, enabling the heterodyne signal to provide high-resolution spectroscopy electronically. The testbed setup developed in this project will enable the continued development of this technique leading to high resolution photonic spectrographs.



1) Heterodyne testbed setup. A broadband source is brought through a HCN reference gas cell with known absorption line spectrum, and mixed with a tunable laser serving as a local oscillator. One beam combiner output is then brought to a photonic Arrayed Waveguide Grating (AWG), and the AWG output channel containing the local oscillator brought to a photodiode, and then oscilloscope, where an electronic Fourier transform of the heterodyne "beat frequency" spectrum provides high-resolution spectroscopy of the selected AWG channel.



2) The spectrum of our EDFA source after passing through the HCN gas cell, showing a forest of absorption lines.

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