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Direct phase measurement of waveguides with a next generation optical vector spectrum analyzer

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Abstract

A novel dual-mode optical vector spectrum analyzer is demonstrated that is suitable for the characterization of both passive devices as well as active laser sources. It can measure loss, phase response, and dispersion properties over a broad bandwidth, with high resolution and dynamic range.

Spectroscopy is one of the most critical characterization technologies for scientific research and industrial engineering¹. Recently, the field has undergone significant development due to growth in the application space that has created strong demand for devices with improved performance, reduced power consumption, and small footprint^{2,3}. As the device platforms become miniaturized, the manifestation of dispersive effects becomes highly significant⁴. This consideration is particularly important in the context of integrated optics⁵. In the presence of these effects careful frequency calibration is required, which can be performed using an optical vector network analyzer.

Optical vector network analyzers characterize the transmission, loss, phase response, and dispersion of a passive device by measuring the linear transfer function⁶. Conventional designs can be broadly grouped into three operating principles: interferometric⁷, optical channel estimation^{8,9}, and sideband modulation^{10,11}. The sideband modulation category can further be broken down into single-sideband and double-sideband devices. Interferometric devices utilize a tunable laser in conjunction with a combination of interferometers, one of which contains the device under test. The transfer function is extracted by performing signal processing on the interferogram. Optical channel estimation devices operate similarly to coherent optical orthogonal frequency-division multiplexing systems, where comparison between transmitted and received symbols is used to infer the transfer function. Sideband modulation devices operate by using an optical passband filter and a modulated probe

laser incident on the device being tested to generate an asymmetric output signal that encodes the transfer function of the device, which can then be reconstructed. In terms of performance, these techniques can achieve a high resolution, however their bandwidth is limited. This renders them unsuitable for characterization of broadband devices such as optical frequency combs, parametric oscillators/amplifiers, and supercontinuum sources.

In a recently published paper in *Light: Science & Applications*, a research team led by Professor Junqiu Liu from the Shenzhen International Quantum Academy has developed a novel dual-mode optical vector spectrum analyzer that is capable of characterizing the transfer function of passive devices, as well as perform analysis on optical sources by coherently mapping an optical spectrum into the radio frequency domain¹². It operates over a broad bandwidth, with high resolution and dynamic range. In this design a chirped laser is either transmitted through a device being tested, or interfered with an optical source being tested. In the case of the device, the transfer function can be extracted by interfering the transmitted signal with that from a reference path. In the case of the optical source, the interference produces a progressive radio frequency beatnote signal from which the spectral information can be recovered. In both cases the output signal is a time-domain interferogram from which the frequency-domain response can be recovered using digital signal processing. The success of this approach requires precision calibration of the chirped laser frequency, which is accomplished by the incorporation of a fiber resonant cavity to acts as a frequency ruler. Remarkably the system does not incorporate any

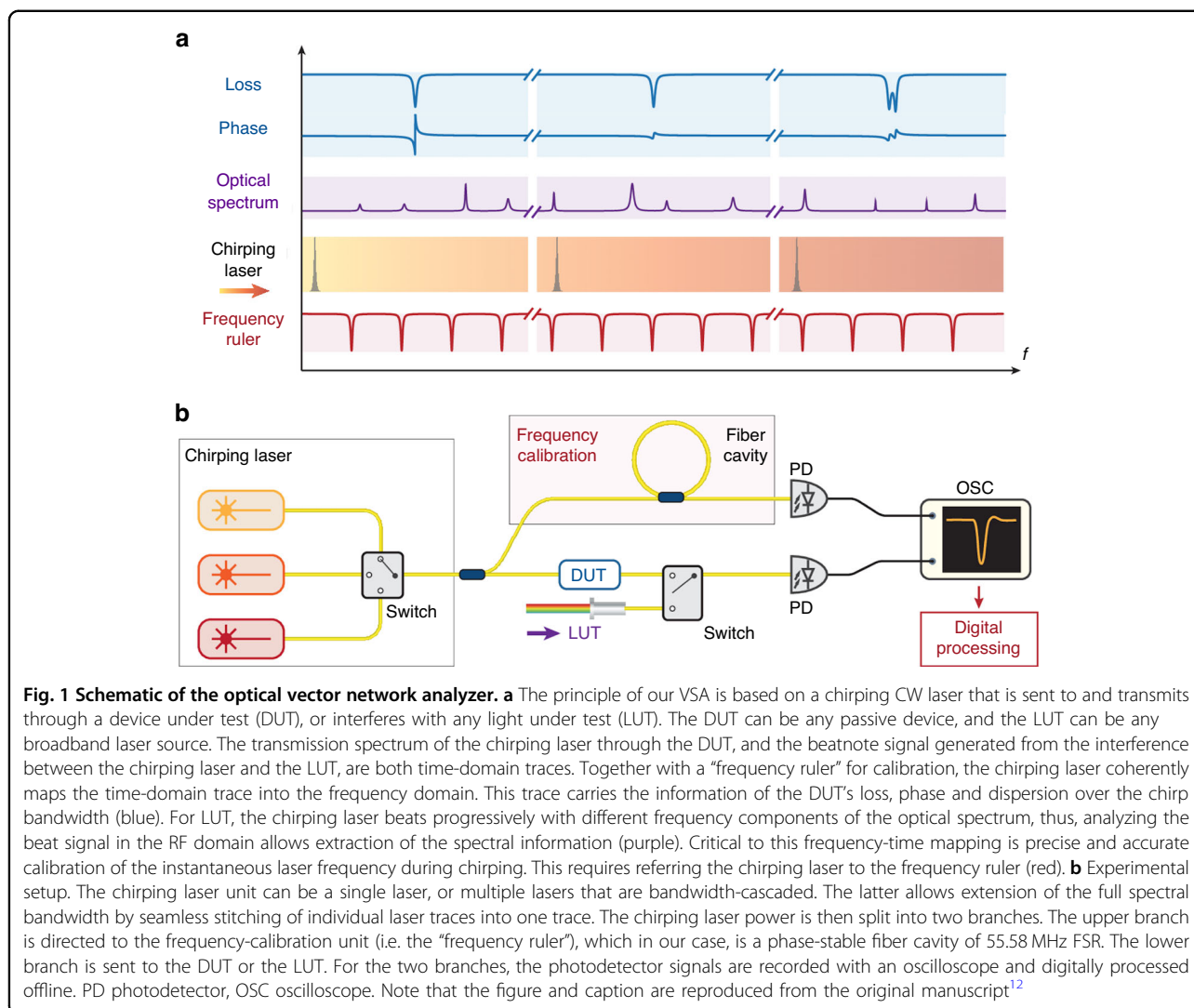
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sort of high-speed modulators/detectors, and it does not require any active feedback mechanism (see Fig. 1 in the original manuscript¹² for a schematic of the device in the configuration for characterizing passive devices, which is reproduced here). The design itself is highly extensible, and can be adapted to other spectral ranges by the addition of appropriate chirped lasers.

Finally, in the paper, it is experimentally demonstrated that with minor modifications the base vector spectrum analyzer system can be employed to additional applications, including light detection and ranging (LiDAR) and mapping frequency comb spectra. It is also speculated that the system can be applied to “... time-stretched systems¹³, optimized optical coherent tomography (OCT)¹⁴, linearization of FMCW LiDAR¹⁵, and resolving fine structures in Doppler-free spectroscopy¹⁶.” This serves to underscore the utility of the design approach, and suggests exciting directions for future research.

Conflict of interest

The author declares no competing interests.

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