High resolution optical spectrum characterization using optical channel estimation and optical frequency combs technique

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Abstract: Characterization of passive optical components based on optical-frequency-combs and optical-channel-estimation using OFDM signals has been proposed firstly. Simulation results show a realized demonstration with the measured range and resolution of ~260 GHz and 19.5 MHz respectively.

OCIS codes: (120.5050) Phase measurement; (060.1660) Coherent communications; (220.4840) Testing.

1. Introduction

Passive optical components can be fully characterized by their transfer functions, including the amplitude (intensity) and phase responses. Several techniques have been commonly used to measure the intensity response, such as optical spectrum analyzer (OSA), laser scanning technique [1, 2]. However, these techniques cannot obtain the phase response and have some limitations of low measurement resolution and/or low measurement speed. Hence, a technique based on optical channel estimation (OCE) using coherent orthogonal frequency division multiplexing (OFDM) signals has been proposed in our previous works [3, 4]. This technique can offer a high-resolution of 0.732 MHz and an ultra-fast measurement speed. But, the maximum measurable frequency range is limited within 12 GHz in wavelength domain. To extend the measurement wavelength range, we have proposed a method to enable the realization of high-resolution and wide-band characterization of passive optical components by applying optical spectrum stitching (OSS) and OCE technique [5, 6]. By using a narrow line-width wavelength-tunable laser source (TLS), a frequency resolution of ~ 10 MHz is realized with an optical measurement range beyond 250 GHz. However, the complexity of the algorithm used in this technique is increased due to the required frequency pilot overlap between the neighboring OFDM sub-bands used to estimate the largely and randomly phase shift of the tunable laser when the wavelength is tuned to the next segment. Meanwhile the tunable laser should be tuned with a very high resolution that increases the cost undoubtedly.

    Here, we present an improved method based on optical frequency combs (OFCs) and OCE using coherent optical OFDM signals to characterize the passive optical components. The OFCs with tunable frequency spacing and fixed relationship between sub-carriers are desired to realize the measurement of the wideband responses of the components at a time. Moreover, the complexity of algorithm can also be reduced by applying OFCs without the need of frequency pilot overlap. In this paper, a device that consists of a delay interferometer with 0.5m long relative arm difference and a Fabry-Perot (FP) filter with 40GHz free spectrum range (FSR) has been characterized. With the simulation of VPI software, we realize a measurement with 19.5 MHz frequency resolution and more than 260 GHz measurement range [7].

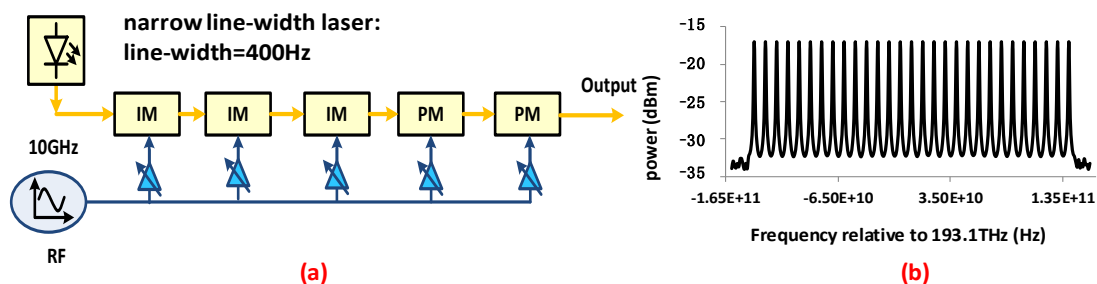## 2. Technique principle and Simulation setup

Fig. 1 (a) Schematic diagram of optical frequency combs generator. (IM: intensity modulator; PM: phase modulator.); (b) the output spectrum of generated OFCs

Fig.1. (a) shows the schematic diagram of the optical frequency combs generator similarly used in [8], which consists of three intensity modulators (IM), two phase modulators (PM), a RF source operated at 10GHz and a narrow line-width laser. Fig.1. (b) shows the output spectrum of the generated optical frequency combs with 27 optical sub-carriers.
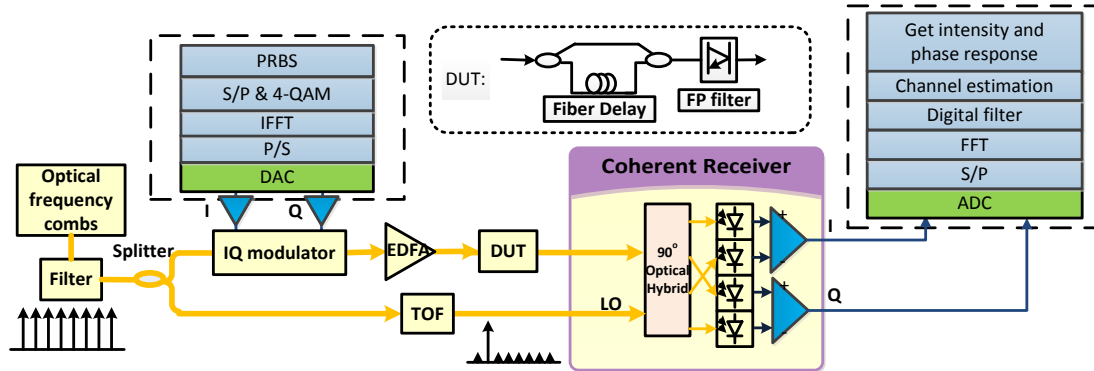

Fig. 2 Simulation setup and the DSP module (S/P: serial to parallel; P/S: parallel to serial; TOF: tunable optical filter; FP: Fabry-Perot; DUT: device under test)

Fig.2 shows the simulation setup and digital signal processing (DSP) module of the measurement system based on the proposed method. The OFCs are firstly split into two branches by a 50:50 splitter, one of them is fed into an IQ modulator biased at null point to generate the stitching 260GHz optical OFDM signal and the other is fed into a tunable optical filter (TOF) to be selected one optical sub-carrier as the local oscillator of coherent receiver. The measurement path includes an erbium-doped fiber amplifier (EDFA) and the device under test (DUT) that consists of a delay interferometer with 0.5m long relative arm difference and a Fabry-Perot (FP) filter with 40GHz free spectrum range (FSR). After passing through the DUT, the sub-carrier of OFDM signal is detected using a coherent receiver. The OFDM symbols are converted to multiple sub-carriers in frequency domain through FFT. Digital signal processing techniques are used to estimate the phase and intensity responses of the OFDM signal induced by passive optical components. By using 512 point FFT, the 19.5 MHz (10 GHz/512) frequency resolution and more than 260 GHz measurement range can be realized. To improve the measurement accuracy, 4-QAM signal is used to map the bit stream data to every OFDM sub-carrier.
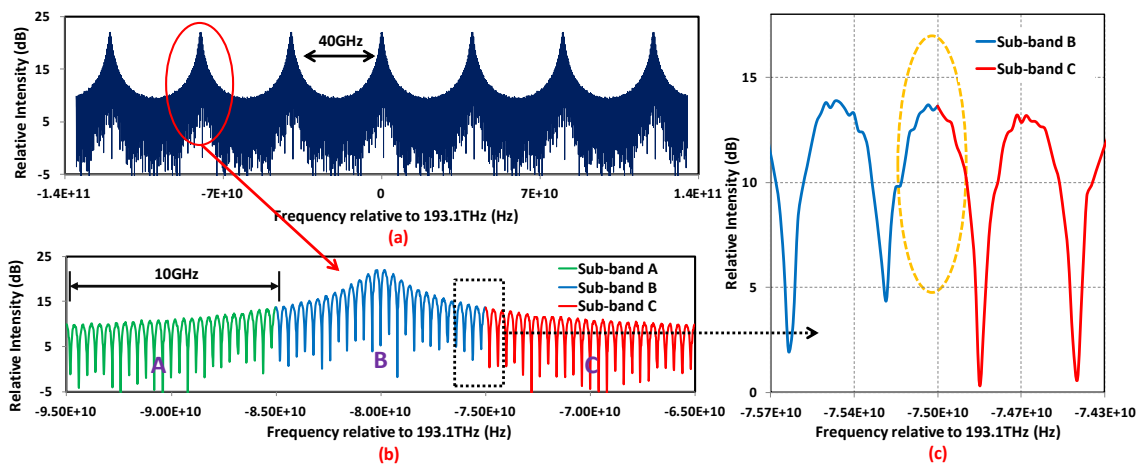
3. Simulation results and Discussion

Fig. 3 The intensity response of the DUT within (a) 260 GHz span, (b) 30 GHz span in detail and (c) 1.4 GHz span in detail.

The proof-of-concept simulation is implemented to characterize a delay interferometer cascaded with a FP filter. The corresponding fine amplitude responses measured by the OCE-OFCs technique within 2 nm (~260 GHz) span are shown in Fig. 3(a). Compared with the OCE-OSS method we proposed before, it is easy for this technique to estimate the response of the joint point of the two adjacent optical OFDM sub-bands. Fig. 3(b) shows the detailed amplitude response of the range circle-marked in Fig. 3(a) within 30 GHz span, which is spliced by 3 blocks of 10GHz OFDM sub-band. The obtained extinction ratio of intensity response is larger than 10dB and the free spectral

range (FSR) is 40 GHz. According to the frequency-dependent power transfer function of DI, the relative delay between the signals in both arms is equal to the reciprocal of FSR. Our result again shows a good agreement with the theory [4]. Fig. 3(c) shows the detailed amplitude response of the joint point of the two adjacent optical OFDM sub-bands. With a fixed phase and frequency relationship of the used OFCs, the two adjacent optical OFDM sub-bands can be simply and accurately spliced.
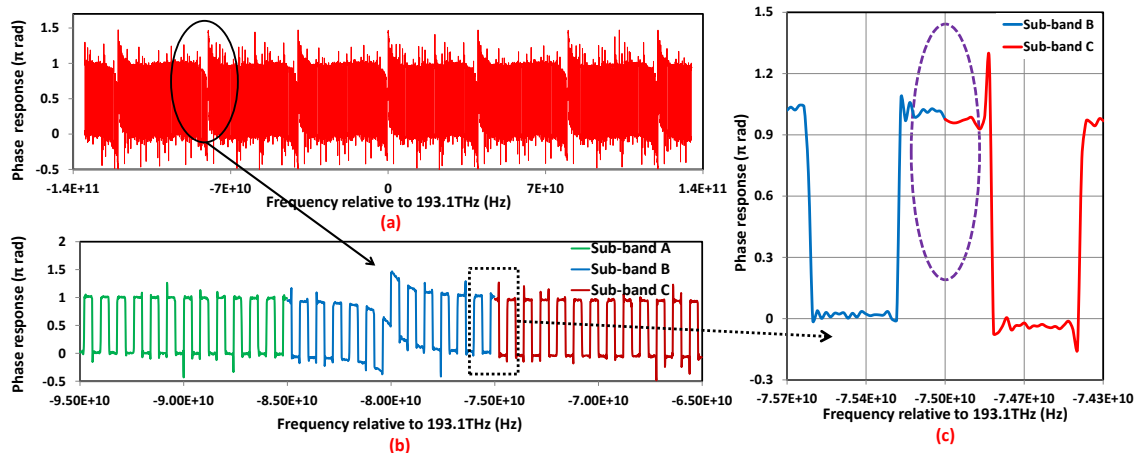

Fig. 4 The phase response of the DUT within (a) 260 GHz span, (b) 30 GHz span in detail and (c) 1.4 GHz span in detail.

Fig. 4(a) shows the simulated phase response of the DUT within 260GHz span. When zoomed in the Fig.4 (a) to a detailed 30GHz span, a periodic phase jumps with a difference level of π caused by the DI phase response can be found in Fig. 4(b). This results show that the phase response of the DI has been accurately obtained. Additionally, there is a phase jump which induced by the FP filter and occurs at the center wavelength of each OFDM sub-band (the peaks position shown in Fig. 3(a)). The phase spikes that do not affect the characterization of passive optical components are not concerned since they just occur at the edge of every phase jump. Fig. 4(c) shows the detailed phase response of the joint point of the two neighboring optical OFDM sub-bands. Obviously, the obtained phase response shows a good continuity between the two neighboring OFDM sub-bands. Based on the advantages of the OFCs with fixed phase relationship, the phase response of the whole desired wavelength range can be spliced together simply and accurately. Compared with our previous work [5-6], the OFCs-based method can improve the measurement performance with the reduced complexity of algorithm and improved accuracy.

4. Conclusion

We have demonstrated a novel method based on optical frequency combs and optical channel estimation technique using coherent OFDM signal to characterize the passive optical components. Through simulation, the characterization of intensity and phase responses of the passive optical components with a 19.5 MHz frequency resolution and a 260 GHz large measurement range has been realized.

Acknowledgements

5. References

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