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Invited Paper

Noise Evaluation of Optical Coherence Tomography with $KTa_{1-x}Nb_xO_3$ Swept Wavelength Light Source

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Abstract. This paper reports on the optical-source noise effect on an interference signal in an optical coherence tomography system with a $KTa_{1-x}Nb_xO_3$ swept wavelength light source. The system can be used to observe a tomographic image of a bio-tissue. The image quality depends on source-signal stability because the tomographic image is obtained by signal processing of the interference signals. We propose a method of evaluating the stability of source and interference signals through fast Fourier transform and statistical calculation. Source-signal stability can be varied by the driving current of the semiconductor optical amplifier (SOA) in the light source. The relationship between source-signal and interference-signal stabilities was investigated by changing the driving current of the SOA. We found that the electrical-interference signal can be evaluated by evaluating the electrical-source signal without an interferometer.

1. Introduction

Optical coherence tomography (OCT) using a light source is a bio-tissue imaging technique [1]. A high-spatial-resolution tomographic image is obtained by OCT with a swept wavelength light source (SS-OCT) [2]. A repetition rate of the light source using a $KTa_{1-x}Nb_xO_3$ (KTN) deflector is 200 kHz [3]. The image quality is based on the source-signal stability because the tomographic image is obtained by signal processing of the interference signal. We investigated the relationship between source-signal and interference-signal stabilities by changing the driving current of a semiconductor optical amplifier (SOA) in the light source to show that improving the source-signal stability improves the interference signal. We propose a method of evaluating the stability of source and interference signals through fast Fourier transform (FFT) and statistical calculation. We argue that the electrical-interference signal can be evaluated by evaluating the electrical-source signal without an interferometer.

2. KTN SS-OCT

Figure 1 shows a KTN SS-OCT system configuration. Light from an SOA is deflected using a KTN deflector. The wavelength of the light from the KTN swept light source is determined from an incident angle to a grating. The split lights in coupler A are interfered with at coupler B. Interference light is converted to an electrical-interference signal in a balanced photo detector (BPD), the electrical-interference signal is converted to a digital signal by using an analog-to-digital converter, and a tomographic image is obtained by signal processing in a signal processor.

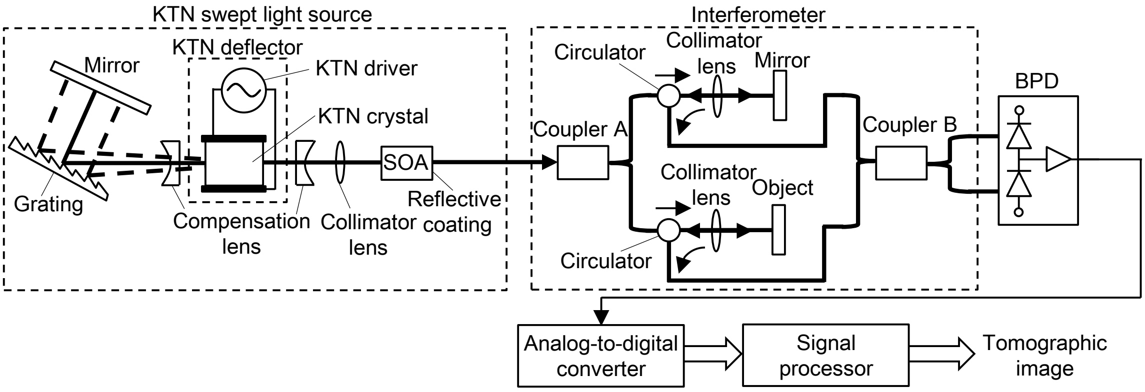


Fig. 1. KTN SS-OCT system configuration.

3. Proposed Method for Stabilities

Figure 2 shows a measurement-block diagram for an electrical-source signal and electrical-interference signal. In Fig. 2 (A), the electrical-source signal is obtained using a PD, amplifier, and low pass filter. In Fig. 2 (B), the electrical-interference signal is obtained using an interferometer, BPD, and band pass filter. The electrical-source and interference signals are evaluated through FFT and statistical calculation.

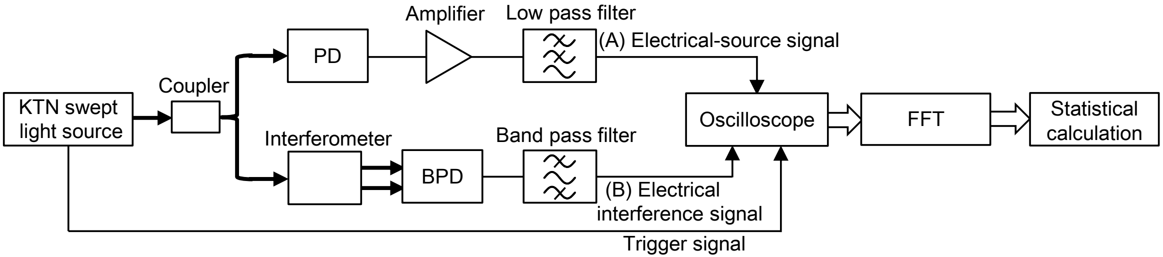


Fig. 2. Measurement-block diagram for electrical-source and electrical-interference signals.

Figure 3 shows the time dependence of (a) the 50th (f = 10.0 MHz) and (b) 52nd (f = 10.4 MHz) harmonics source-signal powers in an observation interval of 50 s and (c) a configuration of the spectra, where N_S is the start order of the harmonics, and N_E is the end order of the harmonics in a detection bandwidth. The fundamental frequency is a repetition rate of a KTN swept light source, which is 200 kHz. Figures 3 (a) and (b) show that the fluctuation ranges of the harmonics differ reciprocally.

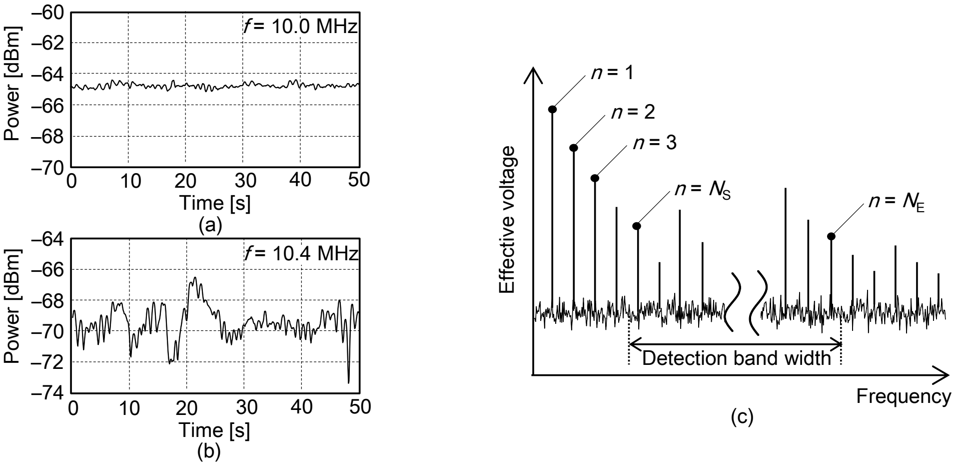


Fig. 3. Time dependence of (a) 50th and (b) 52nd harmonics source-signal powers, and (c) configuration of spectra.

The source-signal variance ${A_{\mathrm{S}n}}^2$ and source-signal stability V_{S} are defined as

$$ {A_{\mathrm{S}n}}^2 = \sum_{i=1}^{M} \frac{(E_{\mathrm{S}ni} - E_{\mathrm{SA}n})^2}{M-1} / \sum_{n=N_{\mathrm{S}}}^{N_{\mathrm{E}}} {E_{\mathrm{SA}n}}^2 , \tag{1} $$

$$ V_{\mathrm{S}} = \sum_{n=N_{\mathrm{S}}}^{N_{\mathrm{E}}} {A_{\mathrm{S}n}}^2 . \tag{2} $$

Here, $E_{\mathrm{S}ni}$ is the effective voltage peak of the n-th harmonic in the i-th (i = 1–M) electrical source signal, and $E_{\mathrm{SA}n}$ is the mean of $E_{\mathrm{S}ni}$ of the M signals.

The interference-signal variance ${A_{\mathrm{I}n}}^2$ and interference-signal stability V_{I} are defined as

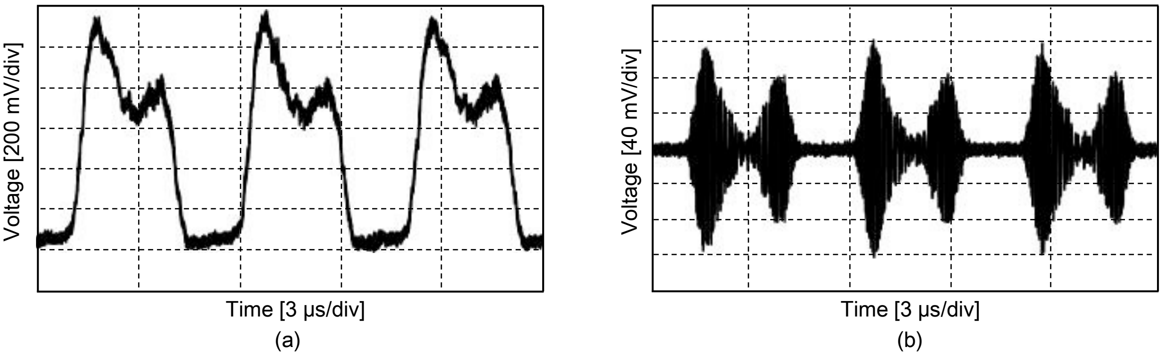
$$ {A_{\mathrm{I}n}}^2 = \sum_{i=1}^{M} \frac{(E_{\mathrm{I}ni} - E_{\mathrm{IA}n})^2}{M-1} / \sum_{n=N_{\mathrm{S}}}^{N_{\mathrm{E}}} {E_{\mathrm{IA}n}}^2 , \tag{3} $$

$$ V_{\mathrm{I}} = \sum_{n=N_{\mathrm{S}}}^{N_{\mathrm{E}}} {A_{\mathrm{I}n}}^2 . \tag{4} $$

Here, $E_{\mathrm{I}ni}$ is the effective voltage peak of the n-th harmonic in the i-th (i = 1–M) electrical interference signal, and $E_{\mathrm{IA}n}$ is the mean of $E_{\mathrm{I}ni}$ of the M signals.

4. Experimental Results and Discussion

Figure 4 shows the measured (a) electrical-source and (b) electrical-interference signals. The SOA driving current was 300 mA in this case.



(a)

(b)

Fig. 4. Measured (a) electrical-source and (b) electrical-interference signals.

Figure 5 shows the spectra of the (a) electrical-source and (b) electrical-interference signals. The main spectra covered a range of less than 10 MHz, as shown in Fig. 5 (a), and a range of less than 50 MHz, as shown in Fig. 5 (b).

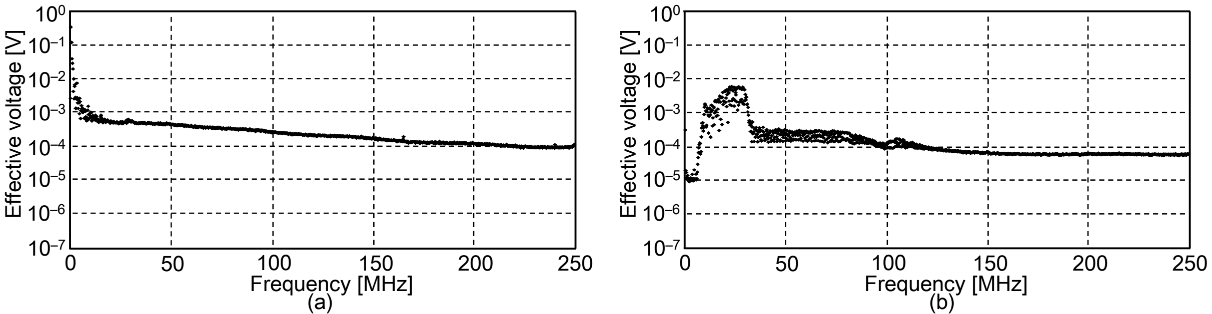


Fig. 5. Spectra of (a) electrical-source and (b) electrical-interference signals.

Figure 6 shows the SOA driving-current dependence of (a) V_S and (b) V_I. The detection bandwidth was from 200 kHz (N_S = 1) to 225 MHz (N_E = 1125) and limited by the low pass filter, as shown in Fig. 6 (a). The detection bandwidth was from 10 (N_S = 50) to 250 MHz (N_E = 1250) and was limited by the band pass filter, as shown in Fig. 6 (b). The V_S and V_I depended on the SOA driving current. The minimum V_S and V_I were obtained when the SOA driving current was 450 mA. The results indicate that interference-signal stability is related to source-signal stability. We found that the electrical-interference signal can be evaluated by evaluating the electrical-source signal without an interferometer.

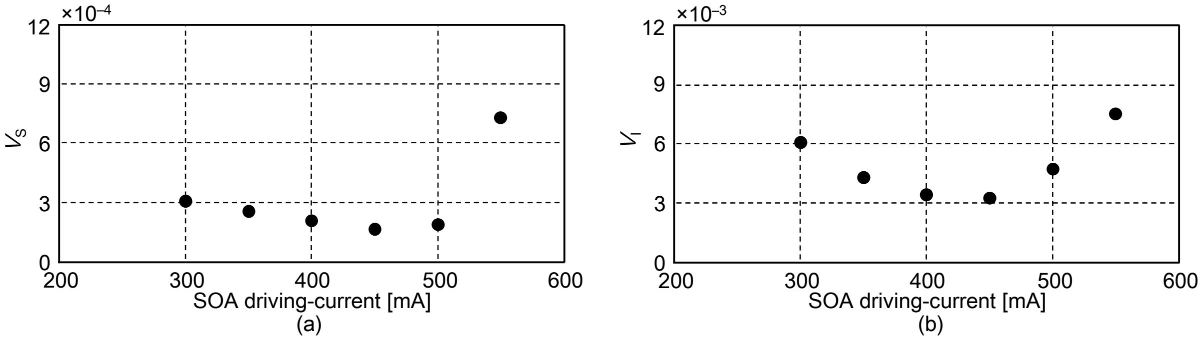


Fig. 6. SOA driving-current dependence of (a) V_S and (b) V_I.

5. Conclusion

We studied the optical source-noise effect on an interference signal in an OCT system with a KTN swept wavelength light source. The relationship between the stabilities of the source and interference signals was investigated by changing the driving current of the SOA. We found that interference-signal stability depends on source-signal stability and that the electrical-interference signal can be evaluated by evaluating the electrical-source signal without an interferometer. In the future, we will examine the relation between source-signal stability and the quality of a tomographic image.

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