The influence of light source linewidth on power spectrum of four light coherent mixing signal

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ABSTRACT

The four-optical coherent mixing detection technology can improve the dynamic range of moving target detection. This method has the difficulty of distinguishing the type of mixing output signal. We propose a method to distinguish the signal type by using the different peaks of the mixed signal spectrum. Based on the statistical theory, the power spectrum function of the mixed signal is obtained, and the numerical analysis of the influence of the light source line width and the light source frequency difference on the signal power spectrum is carried out. Through numerical calculation and analysis, the results show that the increase of the light source linewidth will lead to the broadening of the signal power spectrum. When the Doppler frequency difference is greater than 1/5 times the linewidth of the light source, the power spectrum of the two homodyne coherent signals in the four-light coherent mixing can be distinguished; when the Doppler frequency difference is less than 1/5 times the light source linewidth , The power spectrum of the two homodyne coherent signals in four-optical coherent mixing can not be distinguished.

Keywords: Line width;four-light coherence;moving target;power spectrum;detection

1. INTRODUCTION

Laser coherence detection has the advantages of high sensitivity, high measurement accuracy, high directivity, strong anti-interference ability and so on. It is widely used in target detection, synthetic aperture imaging, velocity measurement and other fields[1-4]. With the continuous progress of technology, the target speed is faster and the Doppler frequency is larger, and the requirements for photoelectric conversion and data processing are higher. Therefore, the conventional laser coherence detection method has been unable to meet the higher detection requirements. Dual-frequency laser coherent detection can be used to convert the higher laser frequency to the lower microwave frequency by the method of optical microwave, so as to achieve higher speed target detection[5-7]. Dual frequency laser coherence detection has better advantages in high precision measurement and has become a hot research field[8-10]. The four-optical coherent mixing detection method can realize the velocity measurement in a larger dynamic range by choosing the appropriate frequency difference and detector[11]. It is difficult to distinguish the output signal type of mixing, and using the signal spectrum is one of the effective methods. Due to the influence of target reflection, atmospheric turbulence, light source linewidth and other factors, the spectrum broadening results in the difficulty of resolving the output signal spectrum. At present, many scholars have carried out research on the influence of light source linewidth on laser coherent detection signal[12-15]. There are few researches on the influence of light source linewidth on the signal spectrum of four-optical coherent mixing detection. In this paper, the dynamic range of velocity measurement of the four-optical coherent mixing detection method is analyzed. In view of the difficulty of discriminating the output signal type of mixed frequency, a method of discriminating by using the signal spectrum is proposed. Combined with the statistical theory, the power spectrum function of the coherent component in the four-optical coherent mixing signal is obtained by using the Wiener - Hinchin theorem, and the influence of the line width, frequency difference and speed of the light source on the signal power spectrum is analyzed numerically.

2. PRINCIPLE OF FOUR-OPTICAL COHERENT MIXING DETECTION

In the four-optical coherent mixing detection method, the assumption of two oscillating light with different frequencies is:

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$$
\begin{aligned}
E_{\mathrm{o}}(\mathbf{r},t) &= E_{\mathrm{o1}}(\mathbf{r},t)+E_{\mathrm{o2}}(\mathbf{r},t) \\
&= U_{\mathrm{o1}}(\mathbf{r})\exp\left\{i\left[2\pi f_{\mathrm{o1}}t+\varphi_{\mathrm{o1}}(t)\right]\right\} \\
&\quad +U_{\mathrm{o2}}(\mathbf{r})\exp\left\{i\left[2\pi f_{\mathrm{o2}}t+\varphi_{\mathrm{o2}}(t)\right]\right\}
\end{aligned} \tag{1}
$$

In the formula, $U_{\mathrm{o1}}(\mathbf{r})$ and $U_{\mathrm{o2}}(\mathbf{r})$ represent the amplitudes of the oscillations of different frequencies; f_{o1} and f_{o2} represent the frequencies of the two oscillations; the frequency difference between the two oscillations is $\Delta f_o = f_{\mathrm{o2}} - f_{\mathrm{o1}}$; $\varphi_{\mathrm{o1}}(t)$ and $\varphi_{\mathrm{o2}}(t)$ respectively represent the random phase of the two oscillations.

In the four-optical coherent mixing detection, the two-reflection signal light of different frequencies is:

$$
\begin{aligned}
E_{\mathrm{s}}(\mathbf{r},t) &= E_{\mathrm{s1}}(\mathbf{r},t)+E_{\mathrm{s2}}(\mathbf{r},t) \\
&= U_{\mathrm{s1}}(\mathbf{r})\exp\left\{i\left[2\pi\left(f_{\mathrm{o1}}+\delta_{\mathrm{o1}}\right)t+2\pi f_{\mathrm{o1}}\tau_{\mathrm{d}}+\varphi_{\mathrm{s1}}(t)\right]\right\} \\
&\quad +U_{\mathrm{s2}}(\mathbf{r})\exp\left\{i\left[2\pi\left(f_{\mathrm{o2}}+\delta_{\mathrm{o2}}\right)t+2\pi f_{\mathrm{o2}}\tau_{\mathrm{d}}+\varphi_{\mathrm{s2}}(t)\right]\right\}
\end{aligned} \tag{2}
$$

In the formula, $U_{\mathrm{s1}}(\mathbf{r})$ and $U_{\mathrm{s2}}(\mathbf{r})$ respectively represent the amplitude of the two reflected signal light, $\delta_{\mathrm{o1}} = 2Vf_{\mathrm{o1}}/c$ and $\delta_{\mathrm{o2}} = 2Vf_{\mathrm{o2}}/c$ represent the Doppler frequency shift, V represents the radial motion speed of the detection target, and c represents the speed of light, τ_{d} is the delay time, $\varphi_{\mathrm{s1}}(t)$ and $\varphi_{\mathrm{s2}}(t)$ represent the random phase of the two reflected signal light.

Two local oscillator lights and two reflected signal lights are mixed on the detector surface. In this paper, only the difference frequency term after mixing is retained. The theoretical four light coherent mixing signal can be expressed as:

$$
\begin{aligned}
I_{\mathrm{c}}(t) &= i_{\mathrm{o}}(t)+i_{\mathrm{s}}(t)+i_{\mathrm{os1}}(t)+i_{\mathrm{os2}}(t)+i_{\mathrm{os3}}(t)+i_{\mathrm{os4}}(t) \\
&= I_{\mathrm{o}}\exp\left\{i\left[2\pi\Delta f t+\Delta\varphi_{\mathrm{o}}(t)\right]\right\} \\
&\quad + I_{\mathrm{s}}\exp\left\{i\left[2\pi\left(\Delta f+\Delta\delta\right)t-2\pi\Delta f\tau_{\mathrm{d}}+\Delta\varphi_{\mathrm{s}}(t)\right]\right\} \\
&\quad + I_{\mathrm{os1}}\exp\left\{i\left[2\pi\delta_{\mathrm{o1}}t+2\pi f_{\mathrm{o1}}\tau_{d}+\phi_{\mathrm{os1}}(t)\right]\right\} \\
&\quad + I_{\mathrm{os2}}\exp\left\{i\left[2\pi\delta_{\mathrm{o2}}t+2\pi f_{\mathrm{o2}}\tau_{\mathrm{d}}+\phi_{\mathrm{os2}}(t)\right]\right\} \\
&\quad + I_{\mathrm{os3}}\exp\left\{i\left[2\pi\left(\Delta f+\delta_{\mathrm{o2}}\right)t+2\pi f_{o2}\tau_{\mathrm{d}}+\phi_{\mathrm{os3}}(t)\right]\right\} \\
&\quad + I_{\mathrm{os4}}\exp\left\{i\left[2\pi\left(\Delta f-\delta_{\mathrm{o1}}\right)t-2\pi f_{\mathrm{o1}}\tau_{\mathrm{d}}+\phi_{\mathrm{os4}}(t)\right]\right\}
\end{aligned} \tag{3}
$$

In the formula, I_{o} , I_{s} and $I_{\mathrm{os}n}$ $(n=1,2,3,4)$ respectively represent the amplitude of the signal after mixing, $\Delta\varphi_{\mathrm{o}}(t)$, $\Delta\varphi_{\mathrm{s}}(t)$ and $\phi_{\mathrm{os}n}(t)$ respectively represent the random phase of the signal after mixing.

In Formula (3), $i_{\mathrm{o}}(t)$ is the difference frequency signal generated by the coherence of the two local vibrators $E_{\mathrm{o1}}(\mathbf{r},t)$ and $E_{\mathrm{o2}}(\mathbf{r},t)$, and its signal frequency is the laser frequency difference Δf ; $i_{\mathrm{s}}(t)$ refers to the differential frequency signal generated by the coherence of two reflected signal light, $E_{\mathrm{s1}}(\mathbf{r},t)$ and $E_{\mathrm{s2}}(\mathbf{r},t)$.In the remote laser coherent detection, the signal component $i_{\mathrm{s}}(t)$ generated by the coherence of two reflected signal light is very small, so the influence of this signal can be ignored; $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ are differential frequency signals generated coherently by $E_{\mathrm{o1}}(\mathbf{r},t)$ and $E_{\mathrm{s1}}(\mathbf{r},t)$, $E_{\mathrm{o2}}(\mathbf{r},t)$ and $E_{\mathrm{s2}}(\mathbf{r},t)$, respectively. $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ can be called homodyne coherent signals. $i_{\mathrm{os3}}(t)$ and $i_{\mathrm{os4}}(t)$ are differential frequency signals generated coherently by $E_{\mathrm{o1}}(\mathbf{r},t)$ and $E_{\mathrm{s2}}(\mathbf{r},t)$, $E_{\mathrm{o2}}(\mathbf{r},t)$ and $E_{\mathrm{s1}}(\mathbf{r},t)$, respectively. $i_{\mathrm{os3}}(t)$ and $i_{\mathrm{os4}}(t)$ can be called heterodyne coherent signals.

According to Formula (3), the frequencies of heterodyne coherent signals $i_{\mathrm{os3}}(t)$ and $i_{\mathrm{os4}}(t)$ are $\Delta f+\delta_{\mathrm{o2}}$ and $\Delta f-\delta_{\mathrm{o1}}$ respectively. When the target moves towards the detection system, the Doppler frequency shift is positive, and when the target is far away from the detection system, the Doppler frequency shift is negative. Therefore, no matter whether the Doppler frequency shift is positive or negative, the frequency of heterodyne coherent signals $i_{\mathrm{os3}}(t)$ and $i_{\mathrm{os4}}(t)$ is always in the form of $\Delta f-|\delta_1|$ or $\Delta f-|\delta_2|$, that is, the signal frequency and the target speed are decreasing, which is a unique feature of four light coherent mixing detection.

According to the photoelectric characteristics, the photoelectric detector has a certain cut-off response frequency f_{c}, and the detector can respond only when the frequency of the mixing signal is less than the cut-off response frequency of the detector [13]. According to Formula (3), the mixing signal component output by the detector is directly related to the cut-off response frequency f_{c} of the detector, the frequency shift Δf of the acousto-optic frequency shifter, and the Doppler frequency shift of the moving target. When $f_{\mathrm{c}}<\Delta f\le 2f_{\mathrm{c}}$, the four light coherent mixing detection system can realize continuous detection of moving targets in a larger dynamic range.

Assuming the laser wavelength $\lambda=532\ \mathrm{nm}$, the cut-off response frequency $f_{\mathrm{c}}=2\ \mathrm{GHz}$, the laser frequency difference $\Delta f=4\ \mathrm{GHz}$, and the Doppler frequency shift is positive, the relationship between the d four light coherent mixing detection signal component and the target radial motion speed is obtained through simulation, as shown in Figure 1.

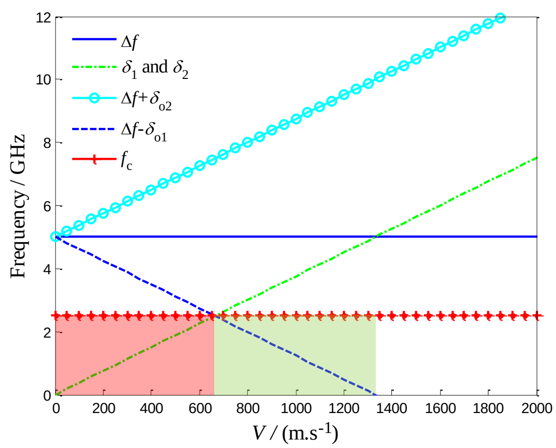
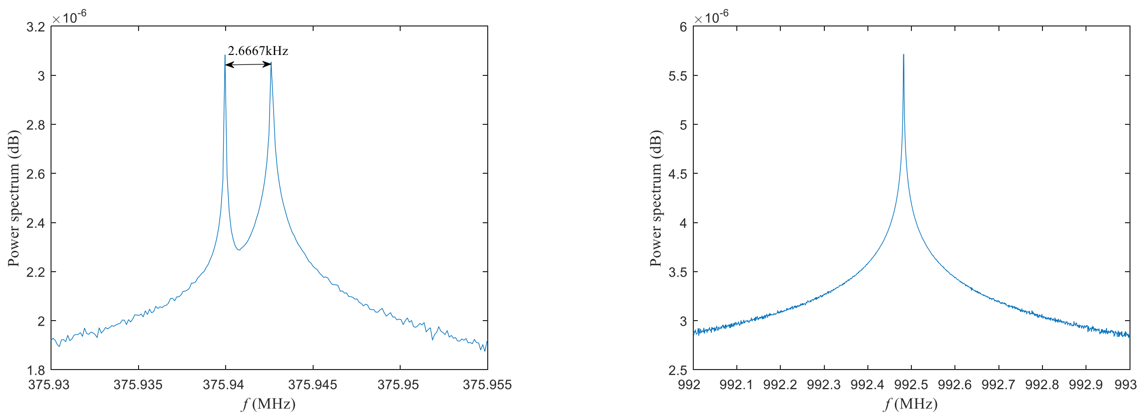


Figure 1 Variation curve of frequency of four-optical coherent mixing detection signal with radial velocity.

It can be seen from the figure that the frequency of signal $i_{\mathrm{o}}(t)$ is a constant invariant. The Doppler frequency shifts δ_{o1} and δ_{o2} of homodyne coherent signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ show a linear increasing relationship with the target speed; The frequency $\Delta f+\delta_{o2}$ of heterodyne coherent signal $i_{os3}\left(t\right)$ also has a linear increasing relationship with the radial velocity of the target. The frequency $\Delta f-\delta_{o1}$ of heterodyne coherent signal $i_{os4}\left(t\right)$ shows a decreasing relationship with the radial motion velocity of the target.

It can be seen from Figure 1 that within the range of the cut-off response frequency f_c of the detector, the velocity value corresponding to the longitudinal axis frequency is not unique. Therefore, how to distinguish whether the signals output by the detector are homodyne coherent signals $i_{os1}\left(t\right)$ and $i_{os2}\left(t\right)$ or heterodyne coherent signals $i_{os4}\left(t\right)$ is an important problem in velocity measurement. When the target's radial motion speed is between 0~532m/s, the output is the homodyne coherent signal components $i_{os1}\left(t\right)$ and $i_{os2}\left(t\right)$. When the target's radial motion speed is between 532~1064 m/s, the output signal is the heterodyne coherent component signal $i_{os4}\left(t\right)$.

Assuming that the target's radial velocity is 100m/s and 1000m/s respectively, the spectrum of the output homodyne coherent signal and heterodyne coherent signal is shown in Figure 2. It can be seen from Figure 2 (a) that the spectrum of homodyne coherent signal component output by the detector contains two adjacent spectral peaks, and the theoretical frequency difference between the two adjacent spectral peaks is 2666.67Hz. However, the spectrum of heterodyne coherent signal components has only one peak, as shown in Figure 2 (b)



(a) $V=100$ m/s　　　(b) $V=1000$ m/s

Figure 2 Signal power spectra at different speeds.(a) Power spectrum of homodyne signal.(b) Power spectrum of heterodyne signal

3. INFLUENCE OF LIGHT SOURCE LINEWIDTH ON SIGNAL POWER SPECTRUM

According to the above analysis, the frequency spectrum δ_1 and δ_2 of signal components $i_{os1}\left(t\right)$ and $i_{os2}\left(t\right)$ can be distinguished in the frequency domain, which is an important basis for judging homodyne coherent signals. In practice, the signal spectrum is affected by the linewidth of the light source, the laser noise and the phase noise caused by the environment. The signal has certain fluctuations and broadening in the frequency domain, which increases the difficulty of signal spectrum resolution [13] [14]. When the frequency difference Δf of the light source is small or the Doppler frequency difference $\Delta\delta$ is small when the moving speed of the target is small, the resolution of the spectrum δ_1 and δ_2 becomes difficult.

In this paper, the homodyne coherent signals $i_{os1}\left(t\right)$ and $i_{os2}\left(t\right)$ are regarded as random stationary signals, and their autocorrelation functions can be expressed as:

$$\begin{aligned} G(\tau) &= \left\langle \left[i_{\text{os1}}(t) + i_{\text{os2}}(t) \right] \left[i_{\text{os1}}^{*}(t+\tau) + i_{\text{os2}}^{*}(t+\tau) \right] \right\rangle \\ &= \left\langle i_{\text{os1}}(t) i_{\text{os1}}^{*}(t+\tau) \right\rangle + \left\langle i_{\text{os2}}(t) i_{\text{os2}}^{*}(t+\tau) \right\rangle \\ &= G_1(\tau) + G_2(\tau) \end{aligned} \tag{4}$$

$$G_1(\tau) = I_{\text{os1}}^2 + \frac{1}{2} I_{\text{os1}}^2 \cos(2\pi\delta_1\tau) \left\langle \phi_{\text{os1}}(t+\tau) - \phi_{\text{os1}}(t) \right\rangle \tag{5}$$

$$G_2(\tau) = I_{\text{os2}}^2 + \frac{1}{2} I_{\text{os2}}^2 \cos(2\pi\delta_2\tau) \left\langle \phi_{\text{os2}}(t+\tau) - \phi_{\text{os2}}(t) \right\rangle \tag{6}$$

$\Delta\phi(t,\tau) = \phi(t+\tau) - \phi(t)$ represents the correlation of random phase noise at different times, which can also be understood as the phase change in time τ . According to the signal noise theory, the random phase change of the signal is a zero mean Gaussian random process, so the following relationship can be obtained [15]:

$$\sigma^2 = \left\langle \Delta\phi^2(t,\tau) \right\rangle = \Delta w_{\text{FW}} |\tau| \tag{7}$$

In the formula, Δw_{FW} represents the full widtd at half maximum of the laser source, $\tau_c = 2\pi/\Delta w_{\text{FW}}$ represents the coherent time, and the relationship between the magnitude of τ_{d} and τ affects the power spectral function of the random signal.

The autocorrelation functions of $i_{\text{os1}}(t)$ and $i_{\text{os2}}(t)$ can be expressed as:

$$G(\tau) = \begin{cases} I_{\text{os1}}^2 + 2I_{\text{os1}}^2 \cos(\omega_{\text{o1}}\tau) \exp(-\Delta w_{\text{FW}}\tau_d) & \\ I_{\text{os2}}^2 + 2I_{\text{os2}}^2 \cos(\omega_{\text{o2}}\tau) \exp(-\Delta w_{\text{FW}}\tau_d) & \tau \geq |\tau_{\text{d}}| \\ I_{\text{os1}}^2 + 2I_{\text{os1}}^2 \cos(\omega_{\text{o1}}\tau) \exp(-\Delta w_{\text{FW}}|\tau|) & \\ I_{\text{os2}}^2 + 2I_{\text{os2}}^2 \cos(\omega_{\text{o2}}\tau) \exp(-\Delta w_{\text{FW}}|\tau|) & -\tau_{\text{d}} < \tau < \tau_{\text{d}} \end{cases} \tag{8}$$

In the formula, $\omega_{\text{o1}} = 2\pi\delta_{\text{o1}}$, $\omega_{\text{o2}} = 2\pi\delta_{\text{o2}}$.

The autocorrelation function of a random signal is an even function. According to the Wiener Sinchen theorem, the autocorrelation function of a random stationary signal and the power spectral density function are Fourier change pairs. Fourier transform formula of signal autocorrelation function:

$$G(f) = 2\int_0^{\infty} G(\tau) \cos(2\pi f\tau) d\tau \tag{9}$$

Take Formula (8) into Formula (9), and get the power spectrum functions of signals $i_{os1}(t)$ and $i_{os2}(t)$ by rounding off the negative frequency components through integral operation:

$$
\begin{aligned}
G(\omega) &= 2\pi\left[I_{\mathrm{os1}}^2+I_{\mathrm{os2}}^2\right]\delta(\omega) \\
&+2\pi\left[I_{\mathrm{os2}}^2\delta(\omega-\omega_{\mathrm{o2}})+I_{\mathrm{os1}}^2\delta(\omega-\omega_{\mathrm{o1}})\right]\exp(-\Delta w_{\mathrm{FW}}\tau_{\mathrm{d}}) \\
&+\frac{2I_{\mathrm{os1}}^2\Delta w_{\mathrm{FW}}}{(\omega-\omega_{\mathrm{o1}})^2+\Delta w_{\mathrm{FW}}{}^2}+\frac{2I_{\mathrm{os2}}^2\Delta w_{\mathrm{FW}}}{(\omega-\omega_{\mathrm{o2}})^2+\Delta w_{\mathrm{FW}}{}^2} \\
&-\frac{2I_{\mathrm{os1}}^2\Delta w_{\mathrm{FW}}\exp(-\Delta w_{\mathrm{FW}}\tau_{\mathrm{d}})}{(\omega-\omega_{\mathrm{o1}})^2+\Delta w_{\mathrm{FW}}{}^2}\left[\frac{\sin(\omega-\omega_{\mathrm{o1}})\tau_{\mathrm{d}}}{\omega-\omega_{\mathrm{o1}}}+\cos(\omega-\omega_{\mathrm{o1}})\tau_{\mathrm{d}}\right] \\
&-\frac{2I_{\mathrm{os2}}^2\Delta w_{\mathrm{FW}}\exp(-\Delta w_{\mathrm{FW}}\tau_{\mathrm{d}})}{(\omega-\omega_{\mathrm{o2}})^2+\Delta w_{\mathrm{FW}}{}^2}\left[\frac{\sin(\omega-\omega_{\mathrm{o2}})\tau_{\mathrm{d}}}{\omega-\omega_{\mathrm{o2}}}+\cos(\omega-\omega_{\mathrm{o2}})\tau_{\mathrm{d}}\right]
\end{aligned} \tag{10}
$$

According to the above formula, the power spectrum of homodyne coherent signals $i_{os1}(t)$ and $i_{os2}(t)$ is related to laser linewidth Δw_{FW}, delay time τ_{d}, Doppler frequency shift δ_1 and δ_2.

4. NUMERICAL SIMULATION ANALYSIS

The power spectra of homodyne coherent signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ in four optical coherent mixing are numerically analyzed and discussed by using formula (10).

In the numerical analysis, if the laser wavelength λ=532 nm and $\tau_d = 0.1\tau_c$ when the target moving speed is 50 m/s and the light source linewidth Δw_{FW} is 3 kHz, 5 kHz and 10 kHz respectively, the numerical simulation results of power spectrum under different light source frequency differences are shown in Table 1.

Table 1 *V*=50 m/s, the numerical calculation results of the power spectrum under different light source frequency differences

Δf /GHz	Theoretical Doppler frequency difference $\Delta\delta$ /Hz	Δw_{FW} =3kHz		Δw_{FW} =5kHz		Δw_{FW} =10kHz	
		Measuring Doppler frequency difference /Hz	Frequency error /Hz	Measuring Doppler frequency difference /Hz	Frequency error /Hz	Measuring Doppler frequency difference /Hz	Frequency error /Hz
1	333.3	\	\	\	\	\	\
1.5	500	\	\	\	\	\	\
1.7	566.7	159.5	407.17	\	\	\	\
2	666.7	443.3	223.37	\	\	\	\
2.5	833.3	711.4	121.93	\	\	\	\
3	1000	923.8	76.20	475.6	524.4	\	\
3.5	1166.7	1115.7	50.97	842.9	323.77	\	\
4	1333.0	1297.6	35.73	1107.2	226.13	\	\
4.5	1500	1474.0	26	1333.4	166.6	\	\
5	1666.7	1647.1	19.57	1539.7	126.97	\	\
5.5	1833.3	1818.4	14.933	1734.4	99.03	\	\
6	2000	1988.2	11.80	1921.2	78.80	951.3	1048.7
6.5	2166.7	2157.3	9.3667	2102.9	63.77	1363.5	803.17
7	2333.3	2325.8	7.53	2281.1	52.23	1685.6	647.73
7.5	2500	2493.8	6.2	2456.6	43.40	1963.5	536.5
8	2666.7	2661.5	5.17	2603.3	36.37	2214.3	452.37
8.5	2833.3	2829	4.33	2802.6	30.73	2447.1	386.23
9	3000	2996.3	3.7	2973.8	26.20	2666.8	333.20
9.5	3166.7	3163.5	3.17	3144.1	22.57	2876.9	289.77
10	3333.3	3330.6	2.733	3313.8	19.53	3079.6	253.73

According to Table (1),when the light source linewidth $\Delta w_{\mathrm{FW}} = 3\,\mathrm{kHz}$ and the laser frequency difference is 1.7GHz, the theoretical Doppler frequency difference is 566.7Hz, and the power spectra of signal $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ can be distinguished. When the linewidth of the light source $\Delta w_{\mathrm{FW}} = 5\,\mathrm{kHz}$ and the laser frequency difference is 3GHz, the theoretical Doppler frequency difference is 1000Hz, and the power spectra of signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ can be distinguished. When the linewidth of the light source $\Delta w_{\mathrm{FW}} = 10\,\mathrm{kHz}$ and the laser frequency difference is 6GHz, the theoretical Doppler frequency difference is 2000Hz, and the power spectra of signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ can be distinguished.

When the motion speed is 50 m/s and 100 m/s respectively, the frequency difference of the light source is F. The numerical calculation results are shown in Table 2.

Table 2 $\Delta f = 4\,\mathrm{GHz}$,the numerical calculation results of the power spectrum under different light source line

line width Δw_{FW} /kHz	50m/s			100m/s		
	Theoretical Doppler frequency difference /Hz	Measuring Doppler frequency difference/Hz	Frequency error /Hz	Theoretical Doppler frequency difference /Hz	Measuring Doppler frequency difference/Hz	Frequency error /Hz
5	1333.33	1107.2	226.13	2666.67	2630.3	36.37
6		886.5	446.8		2595.2	71.47
6.5		710.76	622.57		2570.8	95.87
7		426.42	906.91		2541.2	125.47
7.5		\	\		2505.7	160.97
8		\	\		2463.6	203.07
9		\	\		2357.0	309.67
10		\	\		2214.4	452.27
11		\	\		2025.4	641.27
12		\	\		1773.1	893.57
13		\	\		1421.5	1245.17
14		\	\		852.85	1813.82
15		\	\		\	\

When the motion speed V=50 m/s, the theoretical Doppler frequency difference is $\Delta\delta = 1333.3\,\mathrm{Hz}$. From the numerical calculation results, when the linewidth of the light source is less than or equal to 7 kHz, the peak frequency difference of the power spectrum of signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ can be extracted, that is, the power spectrum of signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ can be distinguished; When the linewidth of the light source is greater than 7 kHz, the peak frequency difference of the power spectrum of signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ cannot be extracted, that is, the power spectrum of signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ cannot be distinguished.

When the motion speed V=100 m/s, the theoretical Doppler frequency difference is $\Delta\delta = 2666.67\,\mathrm{Hz}$. From the numerical calculation results, when the linewidth of the light source is less than or equal to 14 kHz, the power spectrum of signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ can be distinguished; When the linewidth of the light source is greater than 14 kHz,the power spectrum of signals $i_{\mathrm{os1}}(t)$ and $i_{\mathrm{os2}}(t)$ cannot be distinguished.

From the above numerical analysis results, From the above analysis results, it can be concluded that the condition that the power spectrum of signal $i_{os1}(t)$ and $i_{os2}(t)$ can be distinguished is that the theoretical Doppler frequency difference $\Delta\delta$ is greater than 1/5 of the light source linewidth Δw_{FW}. At the same time, when the linewidth of the light source and the moving speed of the target are fixed, the smaller the laser frequency difference, the smaller the theoretical Doppler frequency difference, the greater the difficulty of power spectrum resolution of the homodyne coherent signals $i_{os1}(t)$ and $i_{os2}(t)$, and the greater the error of spectrum resolution.

5. CONCLUSION

In the four light coherent mixing detection, in view of the difficulty in distinguishing the mixing output signal, this paper proposes a method to distinguish by using the power spectrum, obtains the zero difference coherent signal power spectrum model by using the statistical theory, and analyzes the relationship between the light source linewidth, frequency difference, motion speed and the signal power spectrum. Through theoretical analysis, the limit condition that the power spectrum of homodyne coherent signals with different frequencies can be resolved is that the Doppler frequency difference $\Delta\delta$ is greater than 1/5 of the light source linewidth f_{FW}. The research results in this paper show that the four light coherent mixing detection method can achieve a wider range of moving target detection, and theoretically prove that there is a resolution limit for two homodyne coherent signals in the frequency domain. But this research content also needs strict experimental verification, and needs to explore more effective mixed frequency signal discrimination methods.

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