MODIFIED ACOUSTO-OPTICAL SPECTRUM ANALYZER FOR COMPLEX SPECTRUM EVALUATION

Slavinskaya V.V., Tigin D.V.

St. Petersburg State University of Aerospace Instrumentation
67, Bolshaya Morskaya, 190000, St.Petersburg, Russia
E-mail: goule@aanet.ru

Abstract. An approach to implementing an acousto-optical spectrum analyzer for complex spectrum evaluation is considered. The scheme contains the light sources, which emit the information and reference optical beams, and arrays of fibers for accepting optical signals. We discuss the optical coherent heterodyning, which enables to evolve amplitudes and phases of the components of a frequency spectrum, and describe the performance of practical layouts.

Complex spectrum analyzing, Bragg cell, optical coherent heterodyning, fiber-optic delay line.

1. INTRODUCTION

The acousto-optical spectrum analyzer (AOSA) is successfully utilized for evaluation of the power spectrum of radiosignals, received by a panoramic device. Though, in the cases, when the results of the spectrum analysis are used for computer-aided processing, it is necessary to get the complex spectrum. Usually, digital spectrum analyzers compute the complex spectrum. It is well known, that the deficit of computational capabilities arises when signal digital processors are used. Therefore, using of the AOSA, which is capable to operate in a real time, for complex spectrum evaluation is of great interest.

The consecutive type interferential AO spectrum analyzer has been proposed (Ref. 1), which evaluates the complex spectrum. The devise uses two Bragg cells, which have to be identical. The first Bragg cell is fed a controlling chirp signal. We offer to use only one Bragg cell and the optical coherent heterodyning for complex spectrum evaluation. The analysis of the AOSA of this type carried out in this paper enables to estimate characteristics of the device.

2. THE PRINCIPLE OF SPECTRUM COMPONENTS ESTIMATING

Let's consider the principle of the evolving of amplitudes and phases of the spectrum components. Assume, that the Bragg cell is fed a sine signal

$$u(t) = U\cos(\omega_a t + \Phi) \ ,$$

where Φ is the initial phase, U is the amplitude. The collimated beam, which is incident on the Bragg cell, is diffracted. Due to the anti-Stokes interaction the frequency of the light wave increases by the frequency of the acoustic signal, and its phase increases by the initial phase of the acoustic signal

$$s_{sig}(t) = A_1\cos[(\omega_o + \omega_a)t + \Phi + \varphi_o],$$

φ_o is the current phase. The diffracted (signal) wave is focused in the focal plane of the Fourier lens. Assume, that the reference wave is incident on the place of focusing of the diffracted wave. The reference wave can be given by the equation

$$s_{ref}(t) = A_0\cos[\omega_o t + \varphi_o + x].$$

x is a phase delay, which can be controlled. These rays are mixed, if they have the same polarization. The equation for the average intensity is the following:

$$I = 0.5(A_0^2 + A_1^2) + A_0 A_1\cos[\omega_a t + \Phi - x].$$

The light is detected by the photodetector, whose current is proportional to the intensity $i = \eta I$. The dc current may be filtered. If $x = 0$, then the sample of current in the temporal value t_1 is proportional to the cosine component of the harmonic ω_a:

$$i_a = \eta A_0 A_1\cos[\omega_a t_1 + \Phi].$$

If $x = \pi/2$, we get the sample, proportional to the sine component:

$$i_b = \eta A_0 A_1\cos[\omega_a t_1 + \Phi - \pi/2] = \eta A_0 A_1\sin[\omega_a t_1 + \Phi].$$

Knowing the values of η and A_0, we can derive the amplitude of the diffracted beam and its phase incursion

$$A_1 = \frac{\sqrt{i_a^2 + i_b^2}}{\eta A_0}, \ \omega_a t_1 + \Phi = -arctg\left(\frac{i_b}{i_a}\right).$$

3. PRACTICAL IMPLEMENTATION

In practice we analyze a more complicated signal, which produces N diffracted beams. At first, let's consider the reading system. In traditional AOSA, light sources emit long-duration signals, which are detected by the charge-coupled device or the array of photodiodes. These devices have several limitations. It is difficult to read quick changes of the signal spectrum. Besides, the demands to the identity of their photoresponse and dynamic range are difficult to be satisfied. The alternative scheme has been proposed (Ref. 2) for power spectrum evaluation (see Fig.1). The laser emits short pulses (of the order of subnanoseconds), and the light distribution feeds the fiber-optic delay line, connected with the photodetector.

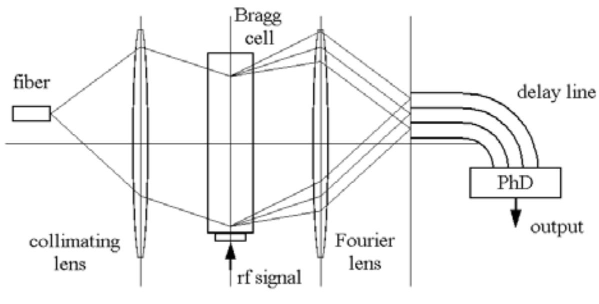


Fig. 1. The optical layout of AOSA with the delay line for power spectrum evaluation

We offer to use this reading system in the AOSA for complex spectrum evaluation. But the one optical pulse gives us only one sample; therefore, we can't filter the dc current. We have to use four reference waves. In the temporal value t_1 we have the following samples from the photodetector:

$$i_{a0} = i_{dc} + \eta A_0 A_1 \cos[\omega_a t_1 + \Phi] \text{ if } x = 0,$$
$$i_{a\pi} = i_{dc} - \eta A_0 A_1 \cos[\omega_a t_1 + \Phi] \text{ if } x = \pi,$$
$$i_{b0} = i_{dc} + \eta A_0 A_1 \sin[\omega_a t_1 + \Phi] \text{ if } x = \pi/2,$$
$$i_{b\pi} = i_{dc} - \eta A_0 A_1 \sin[\omega_a t_1 + \Phi] \text{ if } x = 3\pi/2.$$

From the first two samples we can deliver the ac component i_a, and from the last two terms we can determine the ac component i_b. So, each of N diffracted beams should be divided into four parts, which are mixed with four reference beams. Then, $4N$ beams feed $4N$ polarization-maintaining optical fibers, whose length linearly depends on the frequency. The fibers, which guide the reference waves with the same phase, are connected with one of the four photodetectors. Consequently, we can read successively the assembly of coefficients i_{a0}, $i_{a\pi}$, i_{b0} and $i_{b\pi}$ for each frequency and determine the amplitudes and phases of spectral components.

The possible implementation of the AOSA for complex spectrum evaluation is shown in Fig 2. Here only one reference beam is depicted. Both beams, signal and reference, travel through the Bragg cell. We suppose that acousto-optical interaction is weak. Therefore, the transmitted reference beam doesn't suffer important amplitude and phase fluctuations. This beam illuminates the region, where the diffracted beams are analyzed. The successful operation of this scheme was proved experimentally (see Fig.3). The reference beam may be divided into four parts, and the coefficients may be determined simultaneously. The last figure shows the alternative scheme, where reference beams don't pass through the Bragg cell. Owing to this fact the analyzed radio signal don't influence on their parameters. But the beams don't travel the same path, as the diffracted beams. Therefore, other phase fluctuations may occur.

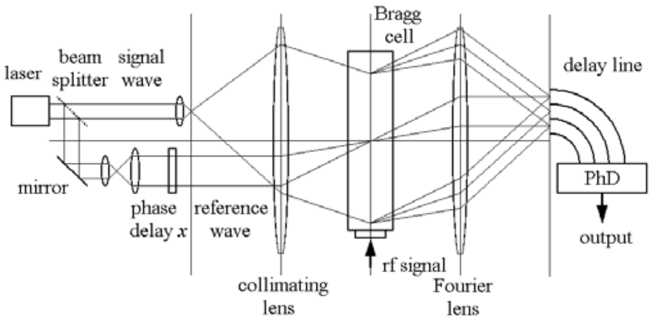
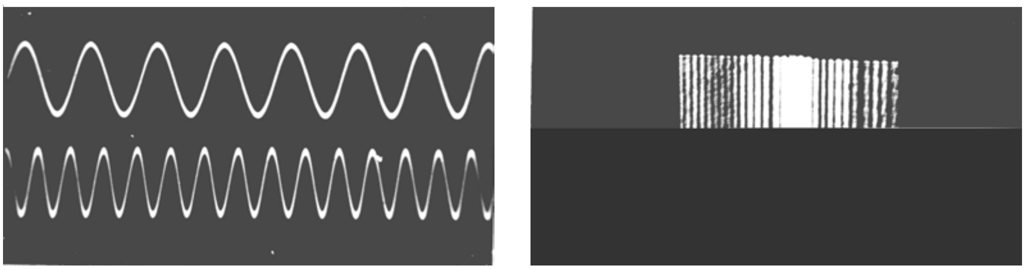


Fig. 2. The optical layout of AO Complex Spectrum Analyzer



a) b)

Fig. 3. The light distribution in the Bragg cell illuminated by the basic and reference beams (a) and the detector responses, when the Bragg cell is fed a superposition of two frequencies (b)

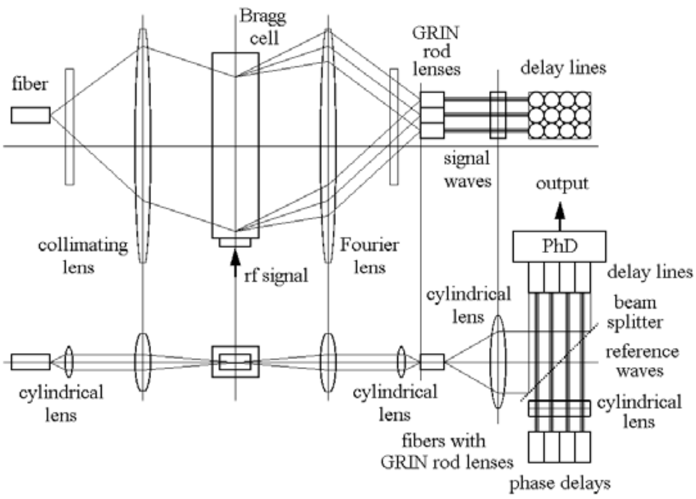


Fig. 4. The alternative optical layout of AO Complex Spectrum Analyzer

Let's summarize the properties of this device**:**

1. Fourier lens performs the Fourier transform with the light velocity
2. A complex spectrum is evaluated due to the optical coherent heterodyning
3. Laser pulse duration is of the order of subnanoseconds, which determines the length of the output pulse τ
4. The pulses from the fiber-optical delay line are detected by the photodetector with the fast response
5. Potentially, the speed of operation approaches to the value of $N\tau$, where N is the quantity of resolvable points.

CONCLUSION

An approach to implementing an acousto-optical spectrum analyzer for complex spectrum evaluation has been considered. The performance of practical layouts and the properties have been described. The device has a relatively simple construction and high speed of performance, which make it worth to be studied in the future.

REFERENCES

1. Preslenev L.N., Razzivin B.P., Tigin D.V. The consecutive type interferential acousto-optical spectrum analyzer of radiosignals// International Forum on Wave Electronics and Its Applications. St.Petersburg: SUAI, 2000, pp. 148-151.
2. Хименко В.И., Тигин Д.В. Статистическаяч акустооптика и обработка сигналов. – СПб.: Издательство С.-Петербургского университета, 1996.