Multichannel acoustooptical spectrum analyzers with the time integration

Martynyuk-Lototska I.Yu., Vlokh R.O.

Institute of Physical Optics, 23 Dragomanova Str., 79005, Lviv, Ukraine,
E-mail: vlokh@ifo.lviv.ua

Received 25.05.2001

Abstract

The multichannel spectrum analyzers on the base of Michelson (with one acoustooptical modulator) and Mach-Zehnder (with two acoustooptical modulators) interferometers in which chirp transformation algorithm are designed and experimentally studied. As multichannel input acoustoptical deflector is used. Experimentally obtained performance characteristics for spectrum analyzer on the base of Michelson interferometer with $PbMoO_4$ acoustooptical deflector and flint glass acoustooptical modulator are: bandwidth Δf=3.3kHz and resolution 55Hz at time integration 20ms; and - on the base of Mach-Zehnder interferometer with TeO_2 acoustooptical modulators and deflector are: bandwidth Δf=9.25kHz, resolution 52Hz at time integration 20ms and 14Hz at time integration 80ms, respectively.

Key words: acoustooptical modulator, acoustooptical deflector, chirp transformation, spectrum analyzer.

PACS: 42.79 Hp 42.79 Jq

1. Introduction

In general case the spectral analysisof the signal S(t) can be described by the Fourier transformation

$$S(\omega)=\int_{-\infty}^{+\infty}S(t)\exp(-i\omega t)dt \qquad (1)$$

where ω - is cycling frequency and t - time. Equation (1) can be rewritten as

$$S(\omega) = exp\left(-i\frac{\omega^2}{2}\right)\int_{-\infty}^{+\infty} S(t)exp\left(-i\frac{t^2}{2}\right)exp\left(i\frac{(t-\omega)^2}{2}\right)dt = exp\left(-i\frac{\omega^2}{2}\right)\left[S(t)exp\left(-i\frac{t^2}{2}\right)\otimes exp\left(i\frac{t^2}{2}\right)\right] \qquad (2)$$

where $\otimes$ - define convolute. Thus the Fourier transformation of signal $S(t)$ is realized by multiplication of the input signal by the linear frequency modulated (chirp) signal $exp(-it^2/2)$ and convolution of this signal with other chirp $exp(it^2/2)$ [1]. This algorithm is called chirp z-transformation algorithm and is the base of the methods of optical signal processing. The principle element of such acoustooptical spectrum analyzer (AOSA) is acoustooptical modulator (AOM) that operates in mode of the Bragg diffraction. It is known few schemes of acoustooptical spectrum analyzer for the Fourier transformation which realize the chirp z-transformation algorithm [1, 4-6]. In these schemes as multichanel input one can use the array of laser diodes. Disadvantage of those systems is necessity of using of the AOM's with wide aperture and little number of parallel channels that are limited by the quantity of elements of array of laser diodes.

Present paper is devoted to studying of the possibility increasing the number of channels in the acoustooptical spectrum analyzer using acoustooptical deflector as multichannel input.

2. Experimental

2.1. Spectrum analyzer on the base of Michelson interferometer with one AOM

The diagram of the AOSA on the base of Michelson interferometer is shown on Fig.1. As the input of the investigated signal of the optical system - acoustooptical deflector AOD-2 is used, that operates in the multichannel diffraction regime [3]. The quantity of spatial channels N in that multichannel AOSA is determined by a number of resolvable position of AOD [2]:

$$N=\Delta fD/v, \qquad (3)$$

where Δf - is the bandwidth of AOD, D - is the aperture of AOD, v – is the velocity of the acoustic wave in the material of AOD. The drive supply of the AOD consists of the generator of carrier frequencies $f_1, f_2,..., f_n$ which belongs to the bandwidth of AOD, amplitude modulators AM_1, AM_2,..., AM_n and adder. The investigated signals $S_1(t), S_2(t),...S_n(t)$ are supplied to input of the driver and are modulate respective signals of the generator of the carrier frequencies. After adding they are supplied to the transducer of AOD-2.

The light beam from laser (1) after the multifrequency diffraction is splitted on the N diffracted beams that make the spatial channels of the AOSA. The spatial position of k-diffracted beam is determinated by the value of the respective carrier frequency f_k according to Bragg condition and its magnitude is modulated by the input signal $S_k(t)$. The diffracted light beams are collimated by the cylindrical lens (3) and spherical lens (4) and sheet beam is propagated through AOM-5. The transducer of AOM-5 is driven by the chirp $expi[w_0t+at^2/2]$, where a is the chip acceleration, $\omega_0 =2pf_0$ is the central frequency. The transmission function of the AOM is

$$t(t,x) = expi[[\omega_0 (t-x/v)+a/2(t-x/v)^2], \qquad (4)$$

where x - is spatial coordinate along the direction of the propagation of the acoustic wave, v - is the acoustic velocity in the material of the AOM. As the result of diffraction on the acoustic wave in each spatial channel light beams 0 and +1 order of diffraction are formed, which are focused by spherical lens (6) on the plane diaphragm (7). Diaphragm plays the role of the spatial filter. As to the diaphragm light beams of +1 diffraction order is collimated by spherical lens (8) and is incident on the beam splitter (9), that split every light beam into two equal-intensity light beams. The light passed through the beam splitter (9) (first arm of interferometer) is reflected by the mirror (10), as well as after the next pass through the beam splitter (9). The reflected light beam (second

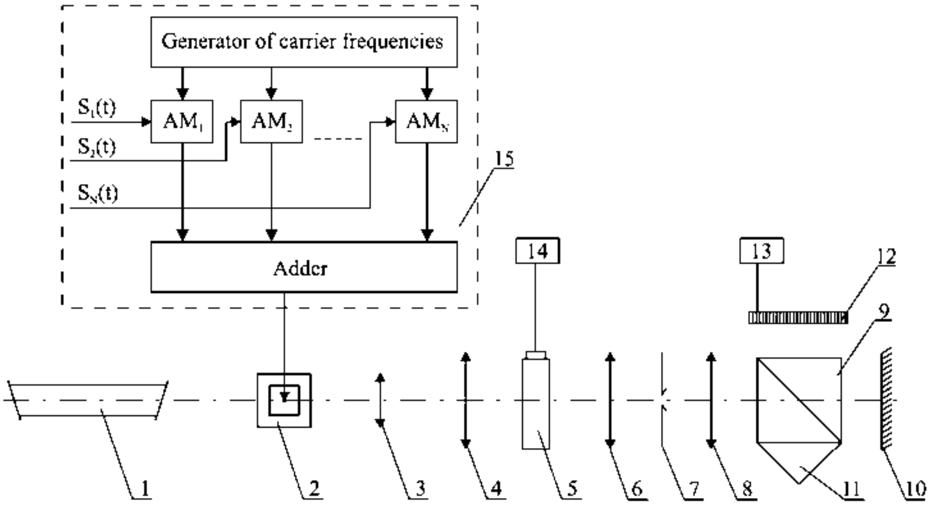

Fig.1.The scheme of the AOSA on the base of Michelson interferometer.

arm of interferometer) is inverted by a roof prism (11) and is passed through the beam splitter (9), where light beams from both arms of interferometer are mixed and are incident on the two dimensional photodetector array (11) and on the *k*-line of this array the image of light beams of the number *k* is formed. The photodetector array provides the time integration. It can be shown that, after a time period *T*, the accumulated charge distribution of the detector array, as a function of spatial coordinate *x*, is given by the expression [4]

$$A_k(x) = p_1 \int_o^T I_k(t)dt + p_2\exp\left(-2i\frac{\omega_o x}{v}\right)\int_o^T S_k(t)\exp\left(-2ai\frac{xt}{v}\right)dt \qquad (5)$$

where p_1 and p_2 are the constants. The first term of Eq.(5) is a signal-dependence direct current term, which can be eliminated by a postdetection processing. The second term is the desired Fourier transformation of the signal $S_k(t)$ modulated a spatial carrier $exp(-2iw_0x/v)$.

The bandwidth of present AOSA is given by the expression

$$\Delta F(x)=2ax/v \qquad (6)$$

and is in the range of $0 \le \Delta F(x) \le 2aD/v$. The frequency resolution is reciprocal to the time integration *T*:

$$\Delta F_{min}(x)=1/T \qquad (7)$$

2.2.Spectrum analyzer on the base of Mach-Zehnder interferometer with two AOMs

The scheme of the AOSA on the base of Mach-Zehnder interferometer differs from the previous one by the two AOMs in two arms of interferometer that are driven by chirp signal. The variation of the time delay between the two chirp signals allows to adjust the bandwidth AOSA in wide range.

The diagram with two AOMs, where every arm of the interferometer are arranged by the AOM and optical system with two lenses and diaphragm is proposed in [7]. Disadvantage of this system is high sensitivity to the external influences, consequently using many optical elements in both arms of the interferometer and necessity of using the same optical elements in every arm of the interferometer. Proposed AOSA (Fig.2) has more simple and compact optical scheme and low sensitivity to the external influences because only one AOM should be in each arm of the interferometer. The optical system is placed behind the interferometer.

As the input of investigated signal to the optical system - AOD-2 is used. The light beam from laser (1) after the process of the multi-frequency diffraction is splitted on the *N* diffracted beams that are formated on the spatial channels of AOSA. The diffracted light beams after

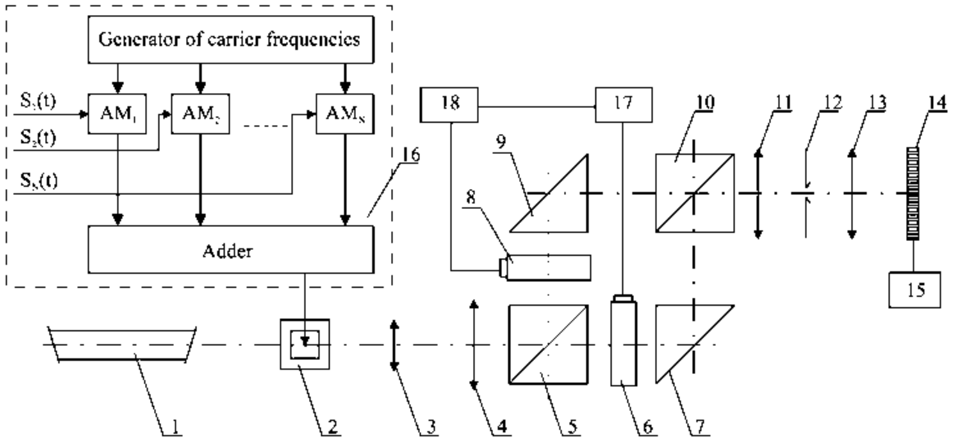

Fig..2.The scheme of the AOSA on the base of Mach-Zehnder interferometer with two AOMs the collimation by cylindrical lens (3) and spherical lens (4) pass the view of the sheet beams and are incident on the beam splitter (5), which split every light beam into two equal-intensity light beams. Beams passed through the beam splitter (5) (first arm of interferometer) are illuminated by the aperture of the first AOM-6. The transducer of AOM-6 is driven by the chirp $expi[w_0t+at^2/2]$ from generator (17). In the result of acoustooptical diffraction on the AOM-6 light beams of 0 and +1 order of diffraction appeared and they are reflected by prism (7) and return to the beam splitter (10).

The beam reflected by the beam spliter (5) (second arm of interferometer) is illuminated by the aperture of the second AOM-8. The chirp signal from generator (17) is applied to the transducer of AOM-8 through delay line (18). Behind the AOM -8 the light beams of the 0 and +1 order of diffraction are reflected by the prism (9) and return to the beam splitter (10), where light beams from both arms of the interferometer are mixed and passed through the lens (11). The lens (11) implements focusing the light beams into plane diaphragm (12). Light beams that are passed through this diaphragm, are obtained in the result of interference as the diffracted beams of the +1 order. The lens (13) focused these light beams as the sheet beams on the two-dimensional photodetectors array (14). The photodetector array provides the time integration. The accumulated charge distribution of the detector array after the time period T, as a function of spatial coordinate x, is described by the expression (5) and contains the desired Fourier transformation of the signal $S_k(t)$.

The bandwidth of the present AOSA is given by the expression

$$\Delta F(x)=a(t_{del.}+2x/v), \qquad (8)$$

where $t_{del.}$ - is a time delay between the two chirp signals which are applied to the AOM-6 and -8.

The bandwidth is in the range of $at_{del.} \leq Df(x) \leq a(t_{del.}+2D/v)$.

3.Experimental results

For the experimental studies of the performance characteristics of the spectrum analyzers the measuring stand is used that include the optical block (AOSA) and electronic blocks: the drive supply of the AOD, the drive supply of AOM (chirp signal generator and line delay), the control system of the photodetectors array and readout.

3.1.AOSA on the base of Michelson interferometer

In the AOSA on the base of Michelson interferometer the following elements are used: single-mode He-Ne laser, acoustooptical deflector on the base of $PbMoO_4$, crystal, (frequency of the supply signal is 160±25 MHz), the flint glass acoustooptical modulator (acoustic velocity is $v=3,63\times10^3$m/c, frequency of the supply signal is 80±10MHz), the 1024-elements linear photodetectors array. From the measured attenuation of the acoustic waves in the AOM follows that the aperture of the AOM equals D=12mm. For the homogeneous illumination of the aperture of AOM the central part of the light beam is used.. The chirp signal with the central frequency f_0=80MHz, bandwidth Δf=10MHz, duration of the sweep T=20ms is applied to the transducer of the AOM.

The bandwidth is defined from (6) and equals 0÷3300Hz, that is confirmed by the experimental measurement. The resolution of this AOAS is experimentally measured and equals 55Hz at the time integration T=20ms, that is in good agreement with the calculated value - $\Delta F_{cal.}$=50Hz.

3.2.AOSA on the base of Mach-Zehnder interferometer

In the AOSA on the base of Mach-Zehnder interferometer the single-mode He-Ne laser, acoustooptical deflector on the base of TeO_2 crystal (frequency of the supply signal is 75.0±12.5MHz, the aperture is 5×3mm), two acoustooptical modulators on the TeO_2 (acoustic velocity is v=616m/s, frequency of the supply signal 75.0±7.5MHz, the aperture 10×3.5mm) and the 1024-elements linear photodetectors array are used.

The bandwidth of this AOSA equals 0÷3250Hz at the chirp signal with the central frequency f_0=75MHz, bandwidth 2MHz and duration of T=20ms. The introducing of the time delay t between the two chirp signals allow to adjust the bandwidth of the AOSA in a wide range. For example, at the time delay τ_{el}=60ms the bandwidth equals 6000÷9250Hz. The experimentally determined resolution of the AOSA on the base of Mach-Zehnder interferometer equals 52Hz at the time integration T=20ms and 14Hz at the time integration T=80ms, respectively that is in agreement with the calculated values - 50Hz and 12.5Hz, respectively.

4.Conclusion

The two schemes of the AOAS with the time integration on the base of the Michelson interferometer and on the base of the Mach-Zehnder interferometer have been modified and demonstrated. Suggested designs have simple optical scheme and low sensitivity to the external influences. We have made the experimental measurements of the performance characteristics of these devices. The resolution of the AOSA is 52Hz at the time integration 20ms and 14Hz at the time integration 80ms, respectively. The improvement of the resolution AOSA may be achieved by increasing the time integration. As the multichannel input of investigated signals the AOD are proposed to be used, that operate in the multichannel diffraction mode. The quantity of spatial channels N in that multichannel AOSA is determined by the number of resolvable position of the AOD (it was shown that it can be more than 200 [2]). Thus, the using of AOD as the input signals creates the possibility to increase the number of channels in the acoustooptical spectrum analyzers and to construct AOSA with the number of channel more than 200.

References

1. Casasent D. and Psaltis D. Appl.Opt. (1980) **19** N126 p.2034 - 2037.
2. Balakshiy V.I., Parigin V.N., Chirkov L.A Physical basis of the acoustooptics Moscow "Radio i svyaz" (1985) 280p. (in Russian).
3. Korpel A. TIIER (1981) **69** N1 p.55-62 (in Russian).
4. Shih-Chun Lin. Appl.Opt. (1982) **21** N18 p.3227-3229.
5. Lin S.– C. US Patent 4.531.197 (1985).
6. Lin S.– C. and Tveten A.B. Opt. Letters (1982) **7** N9 p.448-450.
7. Lee J.N., Lin S. – C. and Tveten A.B. Appl. Phys. Lett. (1982) **41** N2 p.131-133.