

NATIONAL AIR INTELLIGENCE CENTER



FREQUENCY RESOLUTION OF ACOUSTO-OPTICAL SPECTROMETER

by

Wang Jingzheng, Shen Jianjun



Approved for public release;
Distribution unlimited.

1995 0109/29

HUMAN TRANSLATION

NAIC-ID(RS)T-0370-94 16 December 1994

MICROFICHE NR: 94C000569

FREQUENCY RESOLUTION OF ACOUSTO-OPTICAL SPECTROMETER

By: Wang Jingzheng, Shen Jianjun

English pages: 11

Source: Shengxue Xuebao, Vol. 15, Nr. 4, July 1990;
pp. 299-303

Country of origin: China

Translated by: Leo Kanner Associates

F33657-88-D-2188

Quality Control: Nancy L. Burns

Requester: NAIC/TATA/J.M. Finley

Approved for public release; Distribution unlimited.

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE NATIONAL AIR INTELLIGENCE CENTER.

PREPARED BY:

TRANSLATION SERVICES
NATIONAL AIR INTELLIGENCE CENTER
WPAFB, OHIO

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

FREQUENCY RESOLUTION OF ACOUSTO-OPTICAL SPECTROMETER

Wang Jingzheng and Shen Jianjun; Both of Yunan Observatory,
Chinese Academy of Sciences

Abstract This paper discusses the frequency resolution of an acousto-optical spectrometer system under influences of deflector's spectral resolution, coherent light-beam truncation ratio, and photodiode array's response. The broadening of the resolvable line-pattern caused by the response of a photodiode pixel has been computed. According to this discussion the authors proposed the selecting principles for design parameters of the acousto-optical spectrometer including light-beam truncation ratio, focal length of Fourier transform lens, and number of photodiode array elements, i.e. the quantitative criteria for specific observational necessities with an acousto-optical spectrometer considered with resolution, bandwidth, and sidelobes of instrumental profile comprehensively. An experimental measurement of the frequency resolution to verify above theoretical computations has also been carried out.

I. Introduction

With their good features of simple structure, low price, reliability, high sensitivity, high time resolution, broad frequency coverage, and relatively high frequency resolution, acousto-optical spectrometers (AOS) have been finding growing applications in radioastronomical observation, observation of solar radio flares within a wide frequency range from the meter wave region to the submillimeter wave region, observation of molecular spectral lines as well as observation of pulsars and interstellar glow. An AOS performs in all the above-mentioned observations.

Frequency resolution is an important parameter of AOS. Especially in observation of radio spectral lines, the improvement in resolution is one of the main merits of the AOS. The frequency resolution of an AOS is mainly determined by the property of its acousto-optical deflector (AOD), the truncation ratio of the coherent light beam, and the response to the photoelectric diode array (PDA). All the above-mentioned factors have a certain bearing on AOS frequency resolution [1].

II. AIS Frequency Resolution and PDA With Respect to Resolution Line Pattern

1. AOD resolution, side lobe and truncation ratio

The AOD window opening is a long narrow rectangular hole. With respect to a uniformly distributed light beam, and based on the Bragg diffraction relation [2] of acousto-optical interaction, the ultrasonic frequency δf causes deflection of light beam as follows:

$$\delta\theta = \frac{\lambda}{v} \delta f \quad (1)$$

In the equation, v is the propagation speed of an ultrasonic wave in a medium, λ is the wavelength in medium, and the AOD frequency resolution (defined as theoretical resolution) is:

$$\delta f = \frac{v}{D} \quad (2)$$

In the general situation, a laser beam incident to the AOD aperture has a gaussian distribution. If the width of a gaussian light beam $1/e^2$ is d_0 , and the truncation ratio is $\rho = D/d_0$. The Fourier transform of the gaussian function is still a gaussian function. This diffraction light intensity distribution has an approximately gaussian distribution. The light beam divergence angle of the equivalent (to gaussian distribution) is the Rayleigh criterion (the reduction in fringe light intensity is 40.5 percent of the central light intensity) is

$$d\theta = \gamma \cdot \frac{\lambda}{D} \quad (3)$$

Here γ is the field widening coefficient. The resolution of the AOD frequency is

$$df_{AOD} = \gamma \cdot \frac{v}{D} = \gamma \cdot \delta f \quad (4)$$

The value of γ is determined by the truncation ratio of the light beam as shown in Fig. 1. The smaller the value of p , the smaller is γ , and thus the higher the resolution. However, in the case of too small a value of p , the light utilization rate will be too low. However, in the case of astronomy observations, it is more important to have the value of side lobe of the resolution line pattern as small as possible in order to avoid signal confusion. For the $(\sin x/x)^2$ distribution (corresponding to $p=0$), the side lobe is -13dB (the light intensity of the first side lobe is 0.047 times the light intensity of the main lobe). Randolph and Morrison computed the acousto-optic diagram [3] of the gaussian aperture distribution at different truncation ratios. Because of the truncation effect of limited aperture, the side lobe appears in the diffraction diagram. The smaller the truncation ratio, the greater is the side lobe. Hence, for selecting the truncation ratio, consideration should be given to magnitude of resolution, and also to the side lobe effect. For example, when selecting p approximately equal to 1.3 for a side lobe not greater than -20dB (the magnitude of the side lobe is less than 1 percent of the principal lobe). However, the resolution is reduced by only a factor of $\gamma \approx 1.3$.

2. Broadening of resolution line pattern by PDA

The spatial response of PDA picture element can be approximately revealed as a trapezoid function. Since diffraction light of AOD can only be illuminated on a limited number of distributed picture elements, the outline of AOD diffraction diagram will be broadened (thinned) by PDA. Frequency distribution of AOS system is the post broadened (through PSA) resolution of AOD. The distribution of diffraction

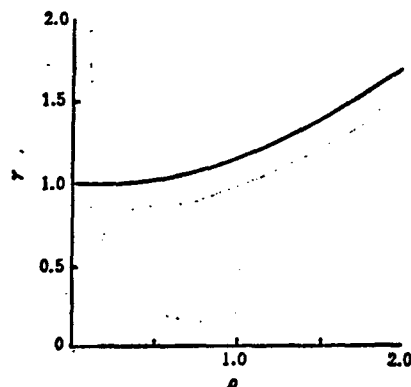


Fig. 1. Relationship of light beam field broadening coefficient and truncation ratio, refer to reference [3]

light intensity (output from the PDA) is equal to convolution of the response by AOD diffraction diagram and PDA pixel:

$$S(x_s) = \int_{\text{pixel}} P(x_s - x) Y(x) dx \quad (5)$$

In the equation, $P(x)$ is the pixel response; $Y(x)$ is the distribution function of the AOD diffraction light intensity; $S(x_s)$ is the relative output of a pixel; x_s is the location of the trapezoidal geometric center on x axis.

Assume that there are N pixels of PDA covered by a half width of the AOD diffraction line pattern.

With respect to the definite values of AOD and PDA, the value of N is determined by the focal length of the Fourier lens. The longer the focal length, the larger is the number N of pixels covered by a certain field angle as distributed on focal plane.

With change of N (in other words, variation of focal length for Fourier lens means a change in the coverage range on the focal plane as distributed by a certain angle) and not considering the absolute magnitude of the focal length, then computation of convolution does not relate to absolute magnitude

of dimensions.

After thinning with PDA, the maximum value of the AOD response equation (5) is

$$S_{\max} = \int_{\text{pixel}} P(x)Y(x)dx \quad (6)$$

As determined by the thinning effect of the PDA, the broadening factor B_r of AOD spatial response can be obtained from numerical computation of the above-mentioned convolution.

Hence, the frequency resolution of the entire AOS system is

$$df_{AOS} = B_r df_{AOD} = B_r \cdot \gamma \cdot \delta f \quad (7)$$

We separately computed the broadening factor of the $(\sin x/x)^2$ type and the gaussian diffraction line pattern by response of PDA pixel. The actual resolution line type lies between these two above mentioned forms. The smaller the truncation ratio, the closer the line pattern to the $(\sin x/x)^2$ type. The greater the truncation ratio, the closer to the gaussian type is the line pattern. B_r is used to indicate the mean value of two types of line pattern broadening factor. Fig. 2 shows the curve relating B_r and N .

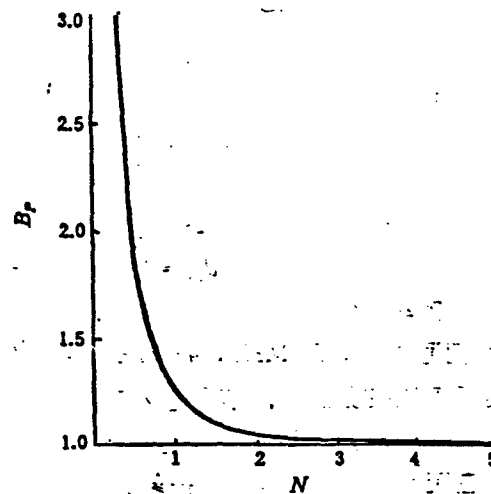


Fig. 2 Broadening of resolution line pattern by PDA

From Fig. 2, when $N=1$, the broadening factor B_r is 1.27. When $N=2$, B_r decreases to about 1.07. After N is greater than 2, the rate at which the broadening factor decreases becomes slower. Therefore, generally N is selected to have a value between 1 and 2. For example, by selecting N equal to 2, the broadening factor is about 1.07; in this case, it is allowed to lower the frequency resolution. When high resolution is not required, such as AOS used in solar radio observations, it is relatively economical to select N equal to 1 [4].

3. Selection of focal length for Fourier lens

When the signal frequency varies within δf , the variation of the light beam deflection angle within the acousto-optic crystal is given by Eq. (1).

For a given pixel number N covered by a half width, the focal length of the lens is

$$F = \frac{Nb\nu}{\lambda_0 \delta f} \quad (8)$$

In the equation, λ_0 is the laser wavelength in vacuo; δf is the theoretical resolution of AOD; and b is the space of a pixel.

In principle, the frequency bandwidth of an AOS is mainly determined by the given working bandwidth of the AOD. As in practice the pixel number of commercial PDAs is divided into some specified levels. In the case of a fixed focal length for a lens, the designer only selects such number of pixels to approximately satisfy the commercial PDA for the AOD bandwidth, thus the effective bandwidth of the instrument is limited to a certain extent. Actually, the lens focal length should also be determined by comprehensively considering the above-mentioned factors.

III. Measurement of AOS Frequency Resolution and Comparison With Theoretical Computation

By adopting a long-focal-length Fourier lens, the relative resolving capability of PDA pixels is higher. The number of pixels occupied by the response of AOS single-frequency signal is relatively high, the measurement of the half-width resolution is relatively precise. By measuring the PDA pixel number occupied by the half-width for the response of a single-frequency signal, the AOS resolution is obtained.

Fig. 3 is an experimental AOS optical path diagram. From a laser source, an emitted light beam has its light intensity adjusted after traversing a polarized lens, then the light beam is incident onto a lens beam expander. An angle is formed between the propagation direction of the expanded light beam and incident light. After reflection by a reflecting mirror, the light beam is deflected, leading to a relatively compact arrangement of the various elements. Following the AOD diffraction, the light beam traverses a lens and is focused onto the PDA. The output of the various pixels is monitored by an oscilloscope. The entire system is installed on a shock-absorbing platform.

1. Measurement of PDA pixel frequency width

The focal length of the lens used is 1455 mm. Adjust the frequency of the single-frequency signal as input onto the AOD transducer, so that the peak value of signal response falls onto pixels of two PDA terminal points successively. The difference of two signal frequencies is the total frequency bandwidth of PDA. By sampling three sets of PDA bandwidth, and 10 samplings for each set, the statistical mean value is derived. The error is expressed by standard error of mean value for sampling of three sets:

$$\Delta f = (10.65 \pm 0.03) \text{ MHz}$$

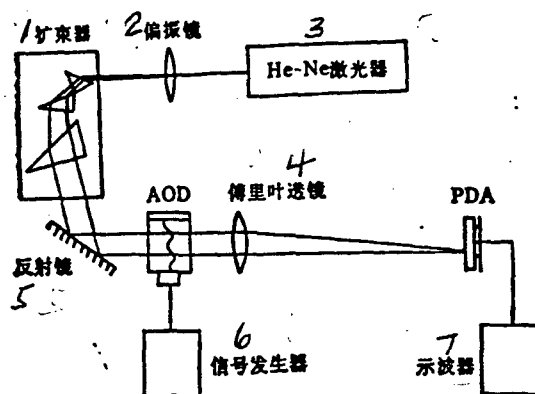


Fig. 3. Experimental AOS skeleton diagram
 Key: 1. Beam expander;
 2. Polariscope; 3. He-Ne laser device; 4. Fourier lens; 5. Reflecting mirror; 6. Signal generator; 7. Oscilloscope.

The number of PDA pixels is 1024; the frequency width of each pixel is

$$\Delta f_p = \Delta f / 1024 = (10.40 \pm 0.03) \text{ kHz}$$

2. Measurement of resolution

From measuring the number of pixels covered by a half-width of the single-frequency signal response at three frequencies (38MHz, 43MHz and 48MHz), the resolution at various frequencies is obtained. The signal input power is 20mW; the output amplitude is adjusted by changing the light intensity. The Bragg angle is fixed to the point of the optimal frequency response. Adjust the oscilloscope so that each lattice corresponds to a pixel. When the peak value of the resolution line pattern falls onto a certain pixel, the pixel number N_0 covered by the half-width is read out from the fluorescent

screen. Measure the pixel several times by changing the peak value. At each frequency, three sets of sampling are taken for statistical mean.

The half-width resolution is

$$\Delta f = N_0 \Delta f_p \quad (9)$$

Table 1 lists the measurement result of resolution experiment.

Table 1. Measurement of AOS Frequency Resolution

$f(\text{MHz})$	N_0	$\Delta f (\text{kHz})$
38	4.12 ± 0.08	42.8 ± 0.9
43	4.19 ± 0.09	43.6 ± 0.9
48	4.23 ± 0.09	44.0 ± 0.9

As discovered in the experiments, the resolution at high frequencies is lower than at low frequencies. This is because the ultrasonic attenuation increases with increasing frequency. Then the high-frequency resolution is lowered somewhat.

3. Comparison with the calculated resolution

For the TeO_2 used by the authors, the effective aperture of the AOD crystal is 20mm; the supersonic speed in the crystal is 650m/s. Therefore, the theoretical resolution (Rayleigh criterion) of AOD is $\delta f = v/D = 32.5\text{kHz}$.

The truncation ratio (of expanded light beam) is $\rho = 1.54$. From Fig. 1, the line pattern broadening (caused by gaussian distribution) is $\gamma = 1.44$.

At center frequency 43MHz, measurement at experiment resulted as follows: the number of pixels N_0 covered by half width is 4.19 (refer to Table 1). It is obtained from Fig. 2 that the corresponding PDA broadening factor $B_p = 1.012$

(corresponding to $N=4.14$).

For diffraction line pattern (of the uniformly distributed incident light), that is the $(\sin x/x)^2$ type, the ratio between the half width resolution and Rayleigh resolution is $\gamma_{HR} = 0.886$.

Hence, the AOS half-width resolution is

$$\Delta f = \gamma_{HR} \cdot \gamma \cdot B_r \cdot \delta f \quad (10)$$

From calculation, $\Delta f = 42.0\text{kHz}$. It was measured in experiments that the resolution at 43MHz is 43.6kHz; the value is in basic agreement with the calculated value.

Coma aberration (caused by asymmetry of the optical path system) and spherical aberration (formed during imaging of a monochromatic broad light beam) will reduce resolution. Besides, optical nonuniformity of the crystal and attenuation of the ultrasonic wave when it propagates through the crystal will have some effect on resolution.

IV. Conclusions

1. The frequency resolution of an AOS is determined by the properties of the AOD, the truncation ratio of the coherent light beam, as well as by the interaction between the PDA pixel response and the AOD single-frequency line pattern convolution.

2. The smaller the truncation ratio of the light beam, the smaller is the effect on resolution. However, meanwhile the profile side lobe of the instrument is increased, thus affecting observational quality. Hence the selection of light beam truncation ratio should comprehensively consider the magnitude of resolution and profile side lobe. The truncation ratio can be selected by changing the increment of beam expansion.

3. The more the number of PDA pixels are covered by the

instrument profile, the smaller the effect on resolution caused by the PDA pixel. However, this will lead to reducing the PDA reception bandwidth. Therefore, we should rely on the main applications of an AOS in thoroughly considering the selection of instrument bandwidth and resolution.

The paper was received for publication on 22 February 1989.

REFERENCES

- [1] Wang Jingseng, (王京生), Robinson, B.J., Huang Gengchen, (黄庚辰), Otturpek, R. E.: 1987, in *Astrochemistry (IAU Symp. 120)*, eds. Vardya, M.S. and Tarafdar, S. P., Reidel, Dordrecht, 135.
- [2] Xu Jieping, Shēngguāng Qíjī Dì Yuánlǐ, Shèjì He Yìngyòng
[Principle, Design and Application of Acousto-optical Devices], Science Publishing House, 1982.
- [3] Randolph, J., Morrison, J., *Applied Optics*, 10, (1971), 1453.
- [4] Wang Jingseng, Xia Zhiguo, Chen Jinying, Jiang Suyun, Min Maolin, Xu Binhuo, Huang Gengchen and Ren Guoxin, *ZHONGGUO KEXUE (SCIENCE IN CHINA, Edition A)*, No. 11, 1986, page 1196.

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

<u>ORGANIZATION</u>	<u>MICROFICHE</u>
B085 DIA/RIS-2FI	1
C509 BALLOC509 BALLISTIC RES LAB	1
C510 R&T LABS/AVEADCOM	1
C513 ARRADCOM	1
C535 AVRADCOM/TSARCOM	1
C539 TRASANA	1
Q592 FSTC	4
Q619 MSIC REDSTONE	1
Q008 NTIC	1
Q043 AFMIC-IS	1
E051 HQ USAF/INET	1
E404 AEDC/DOF	1
E408 AFWL	1
E410 AFDTC/IN	1
E429 SD/IND	1
P005 DOE/ISA/DDI	1
P050 CIA/OCR/ADD/SD	2
1051 AFTT/LDE	1
P090 NSA/CDB	1
2206 FSL	1

Microfiche Nbr: FTD94C000569
NAIC-ID(RS)T-0370-94