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ACOUSTO-OPTICAL SPECTROMETERS AT ITAPETINGA RADIO OBSERVATORY

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ABSTRACT. The characteristics of two low cost acousto-optical spectrometers are presented. They will be used mainly for line work in the frequency range from 20 to 45 GHz. The first instrumental stability tests indicate that integration times lasting several minutes are possible.

Key words; radio spectrometers - acousto-optic.

I. INTRODUCTION

Searches for interstellar molecules have been undertaken at Itapetinga Radio Observatory since the beginning of the last decade. The system used for line study was a filterbank consisting of 64 contigous channels, each one with 100 kHz resolution covering a total bandwidth of 6.4 MHz. This narrow instantaneous bandwidth is a severe limitation for the study of high velocity features of galactic water masers, radio recombination lines, search for molecular maser emission from stars of unknown velocity, and many other problems. In order to reduce these severe limitations we decided to build an acousto-optic spectrometer (AOS)because it could solve the problem of bandwidth in an easier and cheaper way compared to the construction of larger filter bank system or a digital correlator. Several observatories have developed AOS by using Bragg cells containing different acousto-optic mediums like quartz in Australia (Cole and Milne 1977) and water in Finland (Malkamaki, 1981). However, the successful operation of AOS demonstrated by Japanese groups (Kaifu et al., 1977; Kai et al., 1980; Takano et al., 1983), using paratellurite cells, has motivated the development of such system at Itapetinga Radio Observatory.

Historically,Lambert(1962) was the first to describe the principle of an acousto-optic spectrometer. Cole (1973) made the first radio observations using this technique.

Interactions of acoustic-waves and light in an acousto-optical medium can be described in a simple way. A laser beam enlarged by a spatial filter is collimated to illuminate uniformly a crystal (paratellurite) and then focused into a photodiode array. The intermediate frequency (I.F.) of the radio telescope is converted into acoustic wave by a transducer bonded into a crystal and propagates inside it. When the laser beam illuminates a crystal where ultrasonic waves are propagating, the laser beam will be difracted by abnormal Bragg reflection in such way that its intensity distribution is accurately related to the power spectrum of the radio signal.

In this paper the specifications of the components used and the design procedures for the construction of the systems are given.

II. SPECIFICATIONS OF THE AOS

A schematic diagram of the AOS is shown in Figure 1. The optical bench was assembled on a 3 centimeter thick granite table, set in a large dark room, the floor of which was isolated from the rest of the building. On the top of this floor a false floor, not in contact with the table has been build, which enables one to walk around without perturbing the optical bench. A closed cycle, air conditioned system is used in order to keep the room temperature stable to about one degree without making large air turbulences in the room. All parts on the optical bench can be adjusted in the X-Y-Z directions, as well as can be rotated by micrometers.

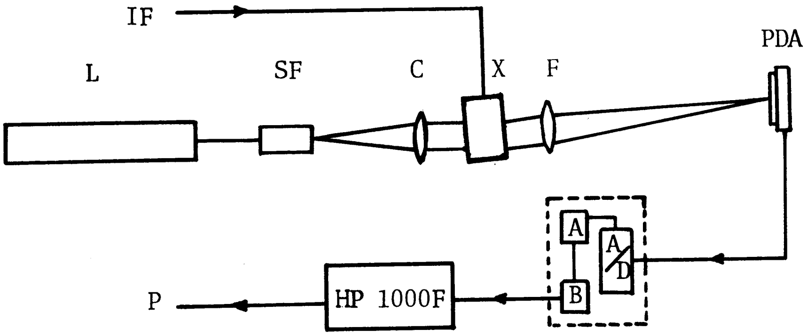

FIGURE 1. Schematic diagram of the AOS at ROI. The main parts are laser (L), spatial filter (SF), collimating lens (C), crystal (X), focusing lens (F), photodiode array (PDA), analog to digital converter (A/D), memories (A,B) main computer (HP 1000F) and peripherals(P). I.F. is the intermediate frequency from the radio telescope.

The 8mW linearly polarized He-Ne (632.8 nm) laser beam is enlarged by a spatial filter and then collimated to illuminate uniformly the window of the crystal. The spatial filter consists of an achromatic microscope objetive lens (with a power of 10X) and a 25μm pinhole that filters out the unwanted higher spatial frequencies of the laser light. The plano-convex lens used to make the beam parallel can be ajusted to illuminate the full size of the crystal window.

The crystals used as the acousto-optic light deflectors are the Matsushita EFL-D750 (AOS-I) and EFL-D1000 (AOS-II). Both are made of paratellurite (TeO_2). The specifications for the crystal used in AOS-I is of 50 MHz deflection bandwidth and 750 resolvable spots, and those for the AOS-II 40 MHz and 1000 spots respectively. The signals from the radio telescope are converted down to an I.F. with the center frequency of 75 MHz and amplified in order to drive the crystal.

A focusing lens is used to direct the difracted spectral image on a Reticon, RL 2048 H, photodiode array (PDA). In order to satisfy the sampling rates after detection, the number of photodiodes of the array should be about three times the number of resolvable spots of the crystal.

The resolution obtained for the system is of the order of 70 kHz (AOS-I), somewhat larger than the 67.7 kHz predicted. The degradation from the theoretical value is probably due to minor misalignement of the optical components. For the AOS-II a resolution of 40 kHz was obtained.

III. NOISE OF THE SYSTEM

The analysis of the output of the PDA is made by a computer after sampling by an A/D converter.However,in order to specify the time of integration per photodiode of the PDA, the number of bits of the A/D converter and the dynamical range of the AOS, we have to analyse the main sources of noise of the system. There are three main sources of normalized noise in the system which have been derived by Kaifu et al. (1980) and are briefly described below. If we assume that the amplifiers of the PDA and following circuits are noiseless and that the saturated output from the PDA is equal to the full-range of the A/D converter:

$$\frac{N_s}{N_{1F}} = \sqrt{\frac{2me\ B\tau}{Q_s}} \tag{1}$$

$$\frac{N_q}{N_{1F}} = m\,\frac{\sqrt{B\tau}}{2^{\ell+2}} \tag{2}$$

$$\frac{N_d}{N_{1F}} = m\tau\sqrt{\frac{0.5\ Be}{Q_s}} \tag{3}$$

where N_s is the shot noise (noise due to the discharge of the PDA), N_q is the quantization noise (due to a ℓ bit A/D converter), N_d is the dark current noise of the PDA, N_{1F} is the noise of the intermediate frequency of the receiver, B is the resolution of the spectrometer, τ is the integration time, Q_s is the saturation charge of the PDA (1.8×10^{-12} coul for the Reticon 2048 H), ℓ is number of bits of the A/D converter, e the electron charge and m is the analogous to the dynamical range of the system. If we want to limit the total contribution of the noise to be about 0.3 dB we must set each noise smaller than 0.3.

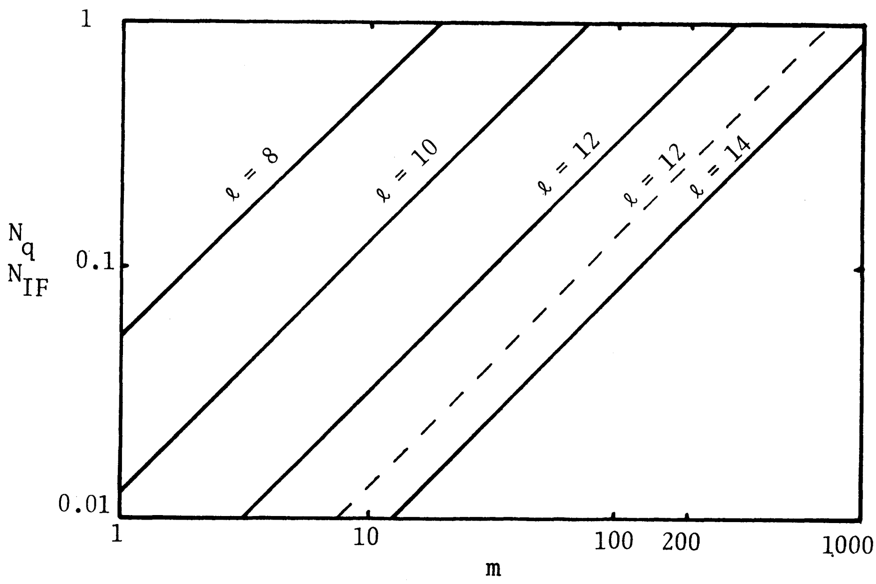

FIGURE 2. Normalized values for the quantized noise for an AOS with B = 70 kHz, τ = 40 ms and several values for the bit number (ℓ) of the A/D converter. The dashed line is this noise for τ = 7 ms.

In Figure 2 we have the solution of Equation 2 for the AOS-I from which we can clearly see how m, the dynamic range, rise with the bit number ℓ and that for a quantization noise contribution of the order of 0.3 a larger number of bits are desirable in order to have higher dynamical range. Assuming that the ratio of the shot noise power to IF power contributes with less than 0.3, for AOS-I (B = 70 kHz and m = 200) we obtain from equation (1) that the integration time should be smaller than 40 ms. The dashed line shows the solution for an integration time of 7 ms for ℓ equals to 12 and we can see that m improves by a large factor compared to the 40 ms line. Figure 3 shows the solutions of Equations 1,2 and 3 for the AOS-I.

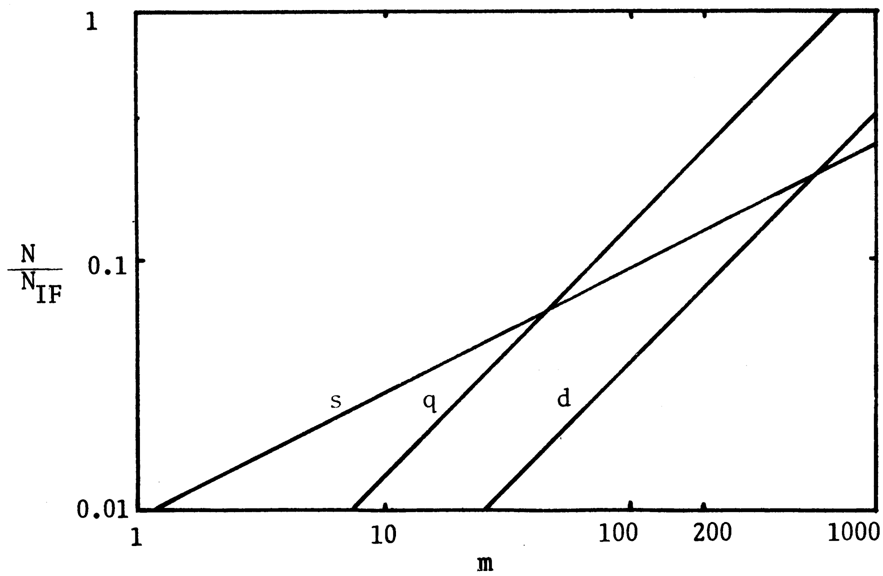

FIGURE 3. Normalized noise for the AOS-I (B = 70 kHz τ = 7 ms) in relative unities. s = shot noise, q = quantized noise and d = dark current noise.

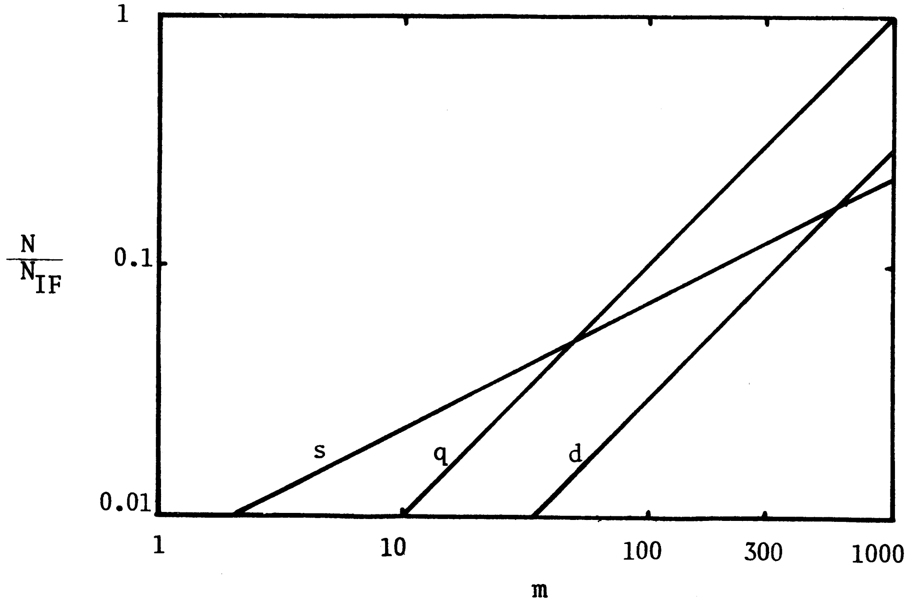

FIGURE 4. Normalized noise for the AOS-II (B = 40 kHz τ = 7 ms) in relative unities. s = shot noise, q = quantized noise and d = dark current noise.

If we set the square root of the summation of the square of the three noises to be about 0.3 and, for example $N_q/N_{IF} \sim 0.28$, $N_s/N_{IF} \sim 0.13$ and $N_d/N_{IF} \approx 0.08$, the dynamic range of the system will be of the order of 23 dB $m \simeq 200$. Figure 4 shows that the dynamic range will be of 25 dB or $m \approx 300$ assuming the same assumptions as above, for the AOS-II (B = 40 kHz).

IV. THE DATA ACQUISITION SYSTEM

A HP1000 F "on line" computer with 576 k bytes of internal memory and a 130 M bytes hard disk unit is available at the Observatory for controlling the various peripherals.

If the transfer of each of the 2048 photodiodes from the Reticon to the computer was to be done in real time, once every 7 ms, we would loose in time access to the computer memory and we could not control any other equipment on time sharing mode.

In order to save computer time and memory, we developed a specific microprogrammed auxiliary unit (UMA). It consists of a fast 12 bits A/D converter (2 μs) and a 32-bit word lenght data storage device, with some basic arithmetic operations capability. The interval memory configuration of this unit is devided in two 2 x 16 bit x 2048 storage areas (A & B), performing very distinctive tasks. The first one (A) is used as a large integration register, and the second (B) as a transfer buffer to the host computer.

By using the two sets of memory arrays, thus allowing fast data transfer while scanning the photo array simultaneously, we recovered the time sharing capability of the computer.

V. FINAL REMARKS

Successful experimental tests carried out with AOS-I and AOS-II show that instantaneous bandwidth of the order of 50 MHz and 40 MHz, with resolution of 70 kHz and 40kHz, respectively, were achieved and both systems will be soon used for line observations.

Further minor modifications will be made in the system in order to try to achieve the theoretical expected instantaneous bandwidth. Slight variations from the theoretical expected instantaneous bandwidth will be achieved by minor implements in the systems.

In order to further improve the instantaneous bandwidth to about 100 MHz, a third AOS similar to AOS-I is being presently developed and will be used in conjunction with it.

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