ESTIMATION OF PERFORMANCE STABILITY OF ACOUSTO-OPTICAL SPECTROMETERS FOR MICROWAVE SWITCHING RADIOMETERS

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ABSTRACT

Performance characteristics of the acousto-optical spectrometers (AOS) for the millimeter-wave radiometers are discussed. The main attention is given to the long-term stability of the acousto-optical spectrometer's characteristics. As to long-term frequency stability it was found that the main part of the frequency scale drifts does not depend on the channel number. So a simple method of the AOS's frequency scale drifts correction by using the data from measuring of a single reference signal's frequency was developed and applied. Long–term amplitude stability estimations are based on the Allan variance method. The Allan dispersion plots were measured for two types of AOS backends of millimeter-wave switching spectroradiometers: (1) AOS-80, including laser diode module, for radioastronomical studies of interstellar gas in molecular lines, and (2) AOS-500 – wideband spectrometer, intended for atmosphere ozone radiation researches. The results obtained are discussed and conclusions about choosing of millimeter wave receiver's parameters in order to optimize the observation efficiency are made.

***Keywords**: switching radiometer, spectrum analysis, acoustooptics, stability estimations.*

1. INTRODUCTION

Spectral measurements based on acoustooptical spectrometers' application are widely used now in the fields where wide instantaneous frequency band and large amount of frequency channels are required. The investigations of Galactic molecular clouds in radioastronomy and atmosphere remote sensing are the essential part of these applications. In both of them the millimeter wave molecular radiation is analyzed in order to determine the main physical and chemical characteristics properties of the separate gas components. Spectral measurements of interstellar dense molecular clouds give the information on dynamical processes at early stages of stellar evolution. Remote sensing of the Earth atmosphere at millimeter waves from the ground level is a highly efficient method of studying the atmospheric composition and processes responsible for ozone layer condition.

AOS's up-to-date spectral coverage and resolution are close to the functional requirements in these fields and the use of acoustooptical spectrometers for spectrum analysis in millimeter wave radio spectroscopy is enlarged. With the requirements for high sensitive radiometer system long time accumulation is needed therefor-high AOS's amplitude and frequency stability is becoming very important. That's why in this work the main attention is given to the long-term stability of the acousto-optical spectrometer's characteristics including the measurements of the AOS's frequency scale drifts and an amplitude stability evaluation.

This report considers mainly the performance of the AOS based backend of the radioastronomical millimeter wave receiver for molecular line observations. Also, some performance characteristics of the wideband AOS intended primarily for microwave remote atmosphere monitoring are considered.

2. AOS BACKEND FOR MICROWAVE SWITCHING RADIOMETER

A functional block-diagram of a typical microwave spectroradiometer with an acoustooptical spectrometer is briefly shown in Fig.1. Conditionally represented here, the system of the input signal switching and calibration provides the modulation mode of operation and calibration of

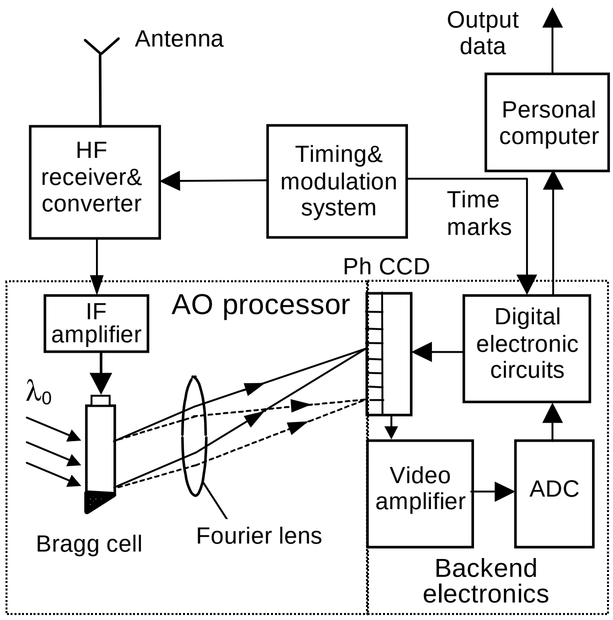

Fig.1 Functional block-diagram of AOS based spectroradiometer

measured spectra. The target signal of the mixer in an intermediate frequency band, after amplification is converted to the AOS's actual band.

AOS consists of two main parts: acousto-optical (AO) processor and data acquisition system. The first one contains AO Fourier processor itself and linear CCD photodetector array. The acousto-optical units are based on the conventional power spectrum analyzer architecture, an example of a typical layout is shown in Fig. 2. This configuration is not very compact but results in a good mechanical and thermal stability. The elements of our AOS are placed on a frame made from aluminum plate of 1.6-cm thickness, in order to reduce the mechanical changes of the optical system. The designed AO processor's mechanical package for both of AOS-80 (80 MHz frequency band, 120 kHz resolution) and AOS-500 (500 MHz band, 0.9 MHz resolution) has a volume of 40x25x12 cm^3. Data acquisition system contains standard personal computer and some special electronic units: CCD photodetector controller, amplifier of CCD video signals, ADC, digital buffer integrator and

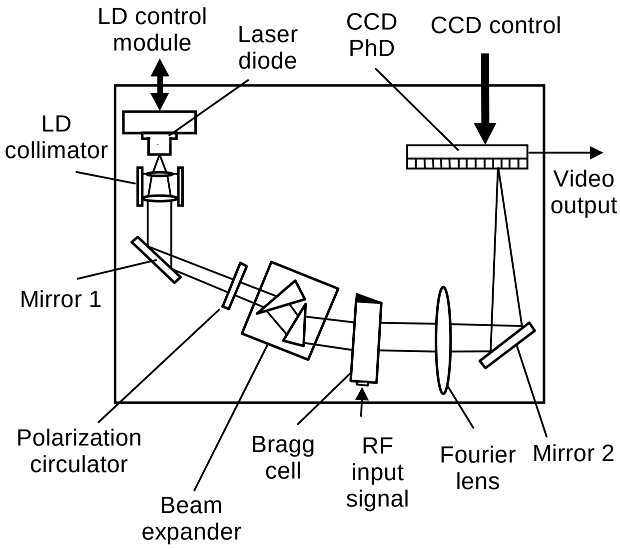

Fig.2 Typical AO processor layout

some others - Ref.-1.
The sensitivity of any radiometer in ideal case is determined by the radiometer formula:

$$\Delta T / T_{syst} = (B \cdot t)^{-0.5}$$

where ΔT is the minimum detectable antenna temperature resulting from signal input, T_{syst} is the total system noise temperature, B is the radiometer channel bandwidth and t is the integration time of the radiometer. So the longer integration time should result in the better sensitivity for the same *B.* In practice the system instabilities degrade the performance of the radiometer from the ideal case and restrict the integration time. In AOS the main perturbing factors are thermal and mechanical deformations. To estimate those restrictions for AOS the Allan variance method was applied -Ref. 2.
Usually, the observer has to find the correct observing parameters in order to use the available hardware in a most effective way. For this the knowledge of the stability parameters is decisive. Some of those instabilities can be eliminated by using the switching procedure (switching radiometer), while others make it necessary to evaluate there influence. Once this information is available from an Allan variance measurement for example, it should be a rather straightforward matter to determine the essential parameters like length of integration per switch position. The examples of such evaluations for the radiometer's AOS backend are given below.

3. AOS'S FREQUENCY SCALE STABILITY

The actual form of the AOS's frequency to channel number dependence (frequency scale) and its variations, mainly influenced by ambient temperature, are of prime importance for AOS's frequency stability evaluation. The linearity of a frequency scale is rather good, slight parabolic non-linearity is less than 0.4% from a full bandwidth for both of AOS-80 and AOS-500. Depending on the application this non-linearity might complicate data analysis, though the problem can be overcome using suitable software. To reduce the frequency scale variations different methods have been proposed and realized earlier. - Refs 3-5. All of them however seem to be rather complicated, that hampers use of an AOS. With our acoustooptic processor's architecture and instrument package it was found that the main part of the frequency scale drifts does not depend on the channel number. So one can use the data obtained from measuring of a single harmonic signal's frequency for acceptable correction of the AOS's frequency scale drifts. This method of frequency calibration was applied for observation data correction - Ref. 6.
During the observations the AOS's response to the calibration signal from a frequency synthesizer has been registered simultaneously. The amendments to the frequency scale are subsequently calculated from the data registered. These shifts of AOS-80 frequency scale, shown in Fig.3, did not exceed ±20 kHz (i.e. ±16% from channel bandwidth) during a full cycle of

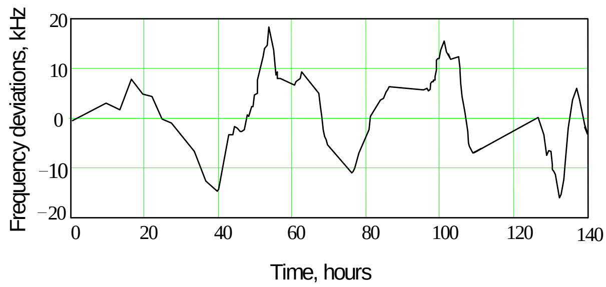

Fig. 3. AOS-80 long-term frequency scale drifts.

observations (more than 180 hours) without any additional efforts on thermostabilisatoin of the AOS package - Ref. 6. The changes of a room temperature during those 180 hours were in limits of ±2.5 degrees.
This illustrates rather good absolute frequency stability of the device. By using of the correction procedure mentioned above the frequency instability could be reduced if necessary to approximately ±3% from channel bandwidth for all channels.

4. AMPLITUDE STABILITY

Long–term amplitude stability was measured for two types of AOS backends of mm-wave switching spectroradiometers: (1) AOS-80 for radioastronomical studies of interstellar gas in molecular lines, and (2) AOS-500 – wideband spectrometer, intended for atmosphere ozone radiation researches. In both of them laser diode modules (LDM) were applied at the preliminary stage of the system design. But while a long-term stability is under consideration some precautions must be taken using LDM. Namely: if a particular laser happens to be in a single longitudinal mode and the temperature is reasonably constant the laser power is actually very quiet, with small noise level. The curves in Fig. 4 shows the typical radiation power vs time dependence for a 650 nm single longitudinal mode LDM during 8000 s from the moment of turning on. The case temperature was stabilized up to a level ±0.2 ^{0}K. AOS's output variations are given in percents of a mean value. One can see that after one hour of warming up those deviations are within ±0.8 %. Unfortunately laser diodes are prone to high levels of mode hop noise independently of thermostabilization. According to our measurements this leads to up to 10 times more AOS output hops. That's why we changed a compact LDM into He-Ne laser in AOS module for long-term observations without saving intermediate data.

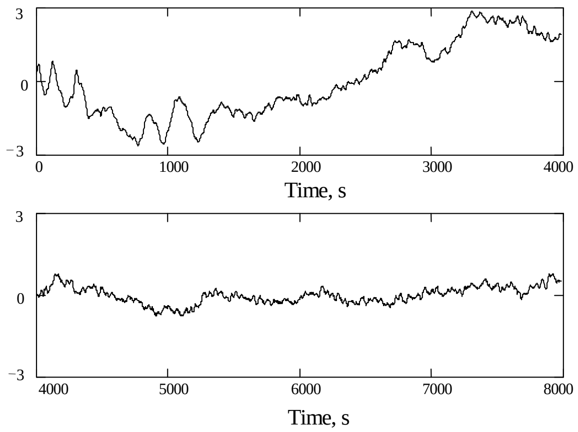

Fig. 4. Time dependence of AOS output deviations (percents of mean value)

Long–term amplitude stability estimations are based on the Allan variance method that has become a standard procedure for the characterization of the quality of high sensitive integrating receivers. The calculations were made by using both of “absolute” and “spectroscopic” Allan variances - Refs. 2,3. An “absolute” Allan variance permits the evaluation of a maximum switching cycle duty for “long-period” switching (for example, beam position switching) or integration period in a compensation mode. A “spectroscopic” Allan variance results in reducing the overall gain variation and gives an estimation of the maximum time interval between amplitude calibrations when “short period” switching mode is applied. Both of the types of the variation plots are displayed in Figs. 5,6. The plots are given for two chosen separate (uncorrelated) spectral channels (Fig.5) and for values averaged on 20 channels (Fig.6). The curves 1, 2 in Fig.5 show, that for both of chosen separate channels minimum of the “absolute” Allan variance corresponds to maximum integration period of about 80 s. This minimum describes the turn-over point where the radiometric noise with a slope of -1 in the logarithmic plot becomes dominated by the additional drift noise.

The “spectroscopic” Allan variance computation where one channel time series is replaced by normalized difference of two uncorrelated channels leads to about 300s integration before minimum occurs (curves 3, 4 in Fig.5). Obviously, a position of a minimum of the “spectroscopic” Allan variance slope in Fig.6 indicates that maximal time interval between amplitude calibrations for “short-period” switching is about 300 sec. As compared with an "absolute" Allan variance minimum position, this

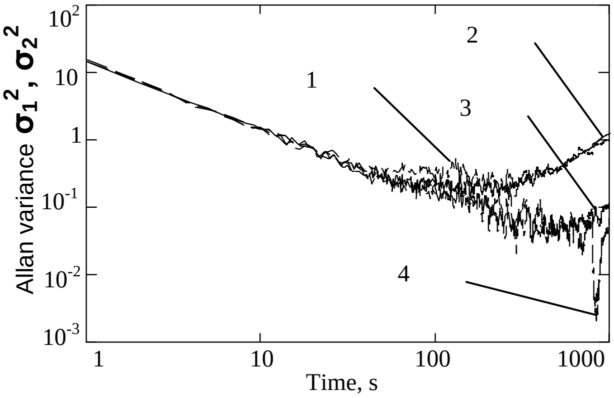

Fig. 5. "Absolute" Allan variance – 1,2 and spectroscopic Allan variance – 3,4 for channels 2 and 14 respectively.

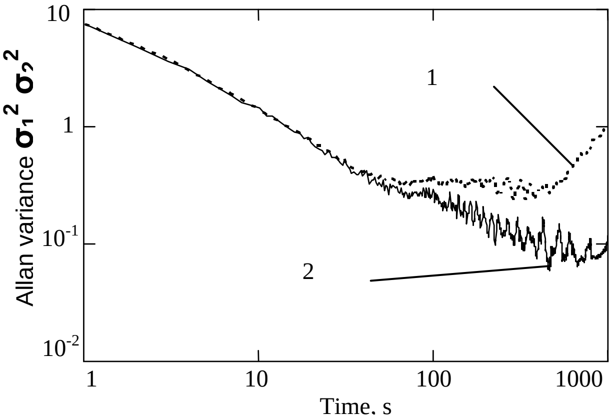

Fig. 6. Averaged for 20 channels "absolute" Allan variance –1 and spectroscopic Allan variance – 2.

reflects the simple fact that the impact of slow drift noise on the signal to noise ratio can be reduced by signal modulation techniques, as is commonly applied during observations in radioastronomy.

CONCLUSION

The performance of AOS backends of switching radiometers was considered. The frequency and amplitude stability of the developed AOS systems has been analyzed. The results obtained are useful for evaluation of the quality of spectroradiometers with AOS and choosing the switching mode timing.

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REFERENCES

1. Esepkina N.A., Kruglov S.K., Molodyakov S.A. - Astronomy & Astrophysics Trans.- 2000. - V.19, NN3-4. - P.616-623.
2. Schieder R., Tolls V., Winnevisser G. - Experimental Astronomy, 1989, N.1, PP.101-121.
3. Lecacheux A., Rosolen C., Dierich P., Paubert G. -Int. Journ. of Infrared and Millimeter Waves, 1993, v.14, N.2, PP.169-183.
4. Masson C.R. - Astron. Astrophys., 1982, N. 114, PP. 270 - 274.
5. Malkamaki L.J., 1984: Observatory and Astrophysics Laboratory, University of Helsinki, Report 1/1984.
6. N.A.Esepkina, I.I.Zinchenko, I.I.Saenko et al.- Izv. vuzov. Radiophysics, 2000, V.43, N.11, PP.935-941. (In Russian)