Performance characteristics of the acousto-optical spectroradiometers for microwave observations

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Among new methods of signal processing in radioastronomy the acousto-optic (AO) ones play an important role. The most significant results were obtained with acousto-optic spectrometers (AOS). From 1973 till now this technique has been considerably improved and now a number of observatories successfully apply various types of AOS as backend systems for the radioastronomical receivers. The low power and cost per channel and simplicity of acousto-optic technology has led to the current development of AOS with bandwidths from tens MHz up to 1 GHz and 1000 channels in small, low power consuming packages. In view of modern acoustooptic spectrometers simplicity, versatility and compactness one can obtain necessary spectrum analysis bandwidth and spectral channels number combining a few AOS (with the same or different parameters) into a multiband system with one or a few of acoustooptical Fourier processors. Besides, this technique is suitable for multibeam receivers. Molecular line observations provide unique information on the physical and chemical state of interstellar medium. The technical requirements to spectral equipment are determined mainly by gas kinetics inside interstellar clouds since the line broadening is caused by Doppler effect. The line widths in so-called high velocity outflow sources reach, $\sim$ 200 km/s i.e. $\sim$ 60 MHz at the wavelength 3 mm. At the same time the thermal line width in cold clouds is only 0.1 km/s, i.e. $\sim$ 30 kHz at the same wavelength. Hence, the AOS's up-to-date spectral coverage and resolution are close to these functional requirements and the AOS-based spectroradiometer's use for spectrum analysis in millimeter wave radio spectroscopy is enlarged. 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.

The receiving complex for millimeter wave spectral line observations at the 22-meter diameter radio telescope (RT–22) of the Crimean Astrophysical Observatory is briefly shown in Fig.1. The RT–22 Cassegrian antenna's system allows to receive radiation in a range from decimeter to millimeter wavelengths with pointing accuracy about 20 arc sec. Conditionally represented in Fig.1, the system of beam switching and calibration located at a surface of the main mirror provides the modulation mode of operation and calibration of measured spectra on radiation of a black body. For millimeter wave observations its front end has been equipped with a cryogenic cooled SIS mixer receiver in 80–120 GHz range. The target signal of the SIS mixer in a intermediate frequency band with the central frequency 1.3 GHz, after amplification is transformed by the second frequency converter

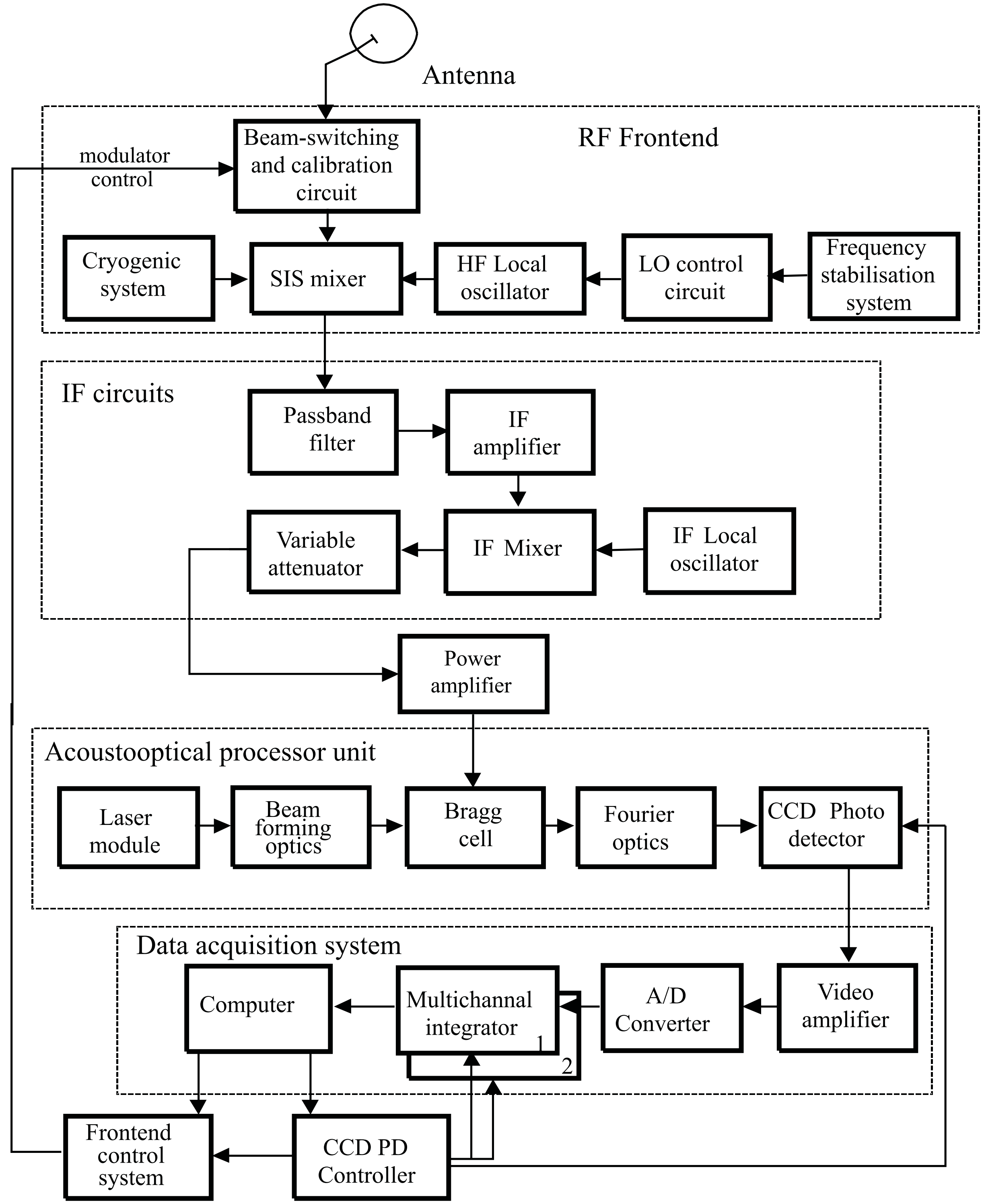

Figure 1: Functional block-diagram of RT–22 receiving complex with AO spectrometer

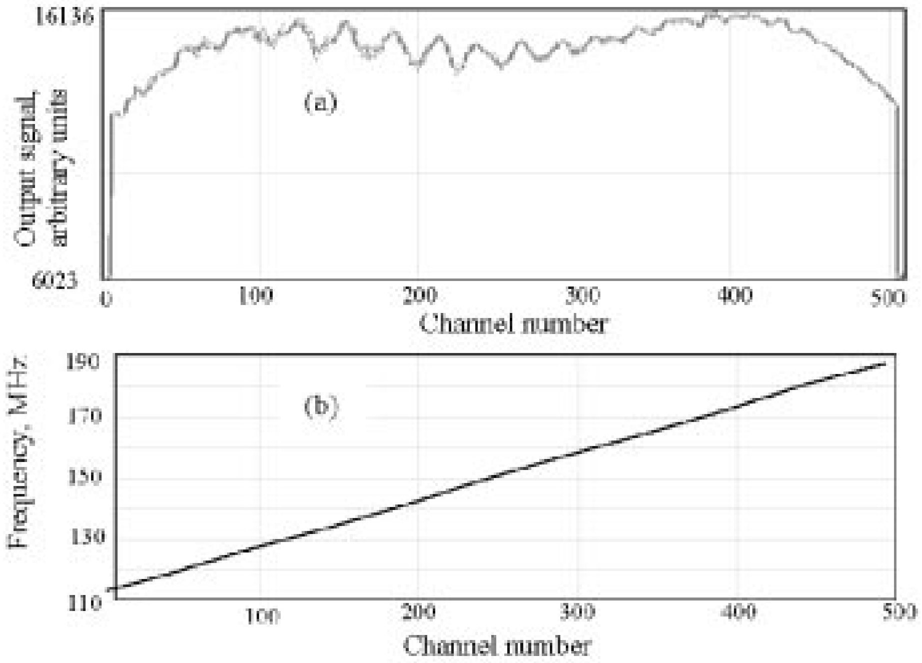

Figure 2: Spectrometer's passband – (a); Frequency calibration – (b)

to the AOS's actual band with the central frequency 150 MHz. Variable attenuator and power amplifier allow to adjust the amplitude of the AOS's input signal.

AOS consists of two main parts: acoustooptic processor unit and data acquisition system. The first one contains AO Fourier processor itself and linear CCD photodetector array. An AO Fourier processor is designed in a traditional mode with folded line optical path and includes, as shown in Fig.1, $He-Ne$ laser, TeO_2 Bragg cell, with 150 MHz central frequency, 8 μsec time aperture and $60\%/W$ efficiency, anamorphotic collimating optics and Fourier transforming lens. At the output plane of AO processor 512-element linear CCD photodetector array with 26×26 μm element size is placed. The designed AO processor's mechanical package has a volume of $40 \times 25 \times 10$ cm^3. Data acquisition system contains standard personal computer and some special electronic units: CCD photodetector controller, amplifier of CCD video signals, digital buffer integrator and some others.

The results of some AOS's characteristics measuring are shown in Fig.2, 3. The curve in Fig.2(a) represents a frequency passband of a complete millimeter wave spectrometer, from the SIS input horn down to the AOS's output. A bandwidth of the analysis is about 76 MHz and every of the 500 spectral channels has, therefore, bandwidth approximately 152 kHz. Some ripples in the upper part of the curve are caused by the light interference at a cover glass of the CCD photodetector. This non-uniformity is eliminated in a course of an amplitude calibration. An example of the AOS's frequency scale calibration is given in Fig.2(b). The linearity of a frequency scale is rather good, weak parabolic non-linearity is less than 0.4% from a full bandwidth. The input signals to be detected are narrowband and extremely weak hence long integration time is necessary to achieve sufficient sensitivity for signal detection. That's why the main attention is given to the long-term stability of the acousto-optical spectrometer's characteristics. Amplitude stability was estimated by means of spectroscopic Allan variance measuring and maximal time interval between amplitude calibrations appeared to be not less than 300 s. 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 one can use the data from measuring of a single harmonic signal's frequency for correction of the AOS's frequency scale drifts. This method of frequency calibration was applied for observation data correction. During the observations the AOS's response to the frequency 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 frequency scale do not exceed ± 17 kHz (i.e. ± 11 % from channel bandwidth) during a full cycle of observations (more than 180 hours). Use of the correction mentioned above results in reduction of frequency instability down to approximately ± 3 % from channel bandwidth for all channels. More details of an application of this calibration method are given in report.

The performance of the receiver and spectrometer system is demonstrated by the spectra of some molecule lines, which have been measured in July 1998. One of them is shown in Fig.3. Given in degrees of main beam temperature the spectral distributions of radiation intensity for molecules CS in Orion on frequency 98 GHz are received as a result of accumulation of a signal during 15 minutes interval. On a horizontal axis of the diagrams Fig.3 both the numbers of AOS spectral channels and appropriate meanings of the velocities of gas molecules are given. In the bottom figure the spectrum of a signal in full spectral band of the analyzer (500 channels) is given, and on top, – a part of a spectrum (124 channels) near of the line center.

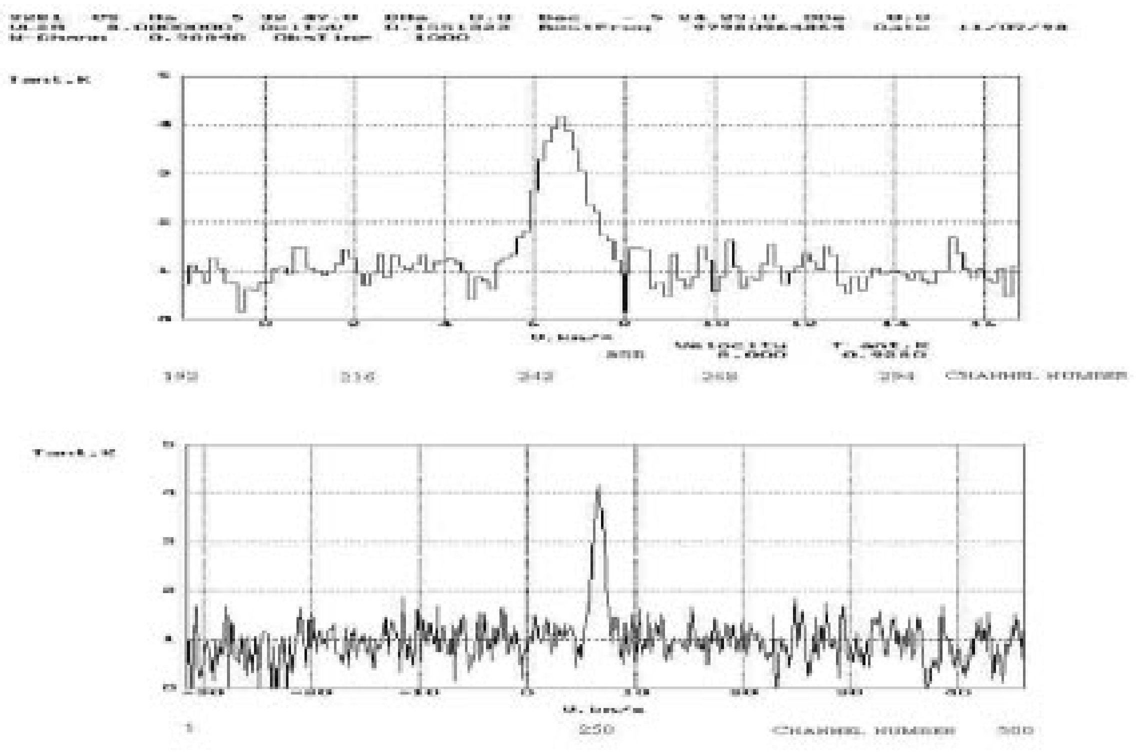

Figure 3: Thermal CS emission at 97.981 GHz from S281 with AOS