ACOUSTOOPTICAL PROCESSOR FOR PULSAR RADIOEMISSION OBSERVATION

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ABSTRACT

The new type acoustooptical processor for observation weak radioemission from cosmic sources - pulsars is developed. The processor is conveyor type one. It works like 600-channel filter bank receiver with noncoherent (after detection) dispersion compensation in real time. It used for the first time at Russian radio telescope THA-1500 (Kalyasin, Moscow region).

Keywords: acoustooptical radiosignal processor, acoustooptic spectrum analyzer, CCD photodetector, scanning operation mode, pulsars.

1. INTRODUCTION

Now at developing high-performance data processing systems the large attention is given to usage of optical and, in particular, acoustooptical (AO) of processors [1,2]. One of applications, where acoustooptical processors have shown the efficiency at processing of wideband signals, is the radioastronomy. Many radiotelescopes are equipped with broadband AO spectrum analysers with number of channels up to 1000 and more [3]. Other example of effective application of AO spectrum analyser is the acoustooptical system for multibeam diagram formation in the Siberian Solar radio telescope - radioheliograph [4]. This AO system allows to receive the radiomap of the Sun in real time with high spatial and time resolution. The application of multichannel AO spectrum analyser in broadband receiving system for observation of radio emission from pulsars is known also [5]. However processing of output signals of all frequency channels with the purpose of dispersion influencing elimination is fulfilled after it by conventional manner: not in real time - after observation ending.

We offer new type AO processor for observation of pulsars, in which dispersion influence compensation is implemented in a real time owing to usage of multielement CCD-photodetector in special operational mode.

2. FEATURES OF PULSAR RADIOEMISSION

In observation radioastronomy one of research objects are the pulsars [5,6]. They are neutron stars with high and very stable rotation rate. The radioemission of pulsars has some properties, which one complicate creation of receivers for their observation: small flux *S*, different pulse repetition periods T_P, dispersion of radiation *DM* in interstellar medium (see Tabl.1).

Table 1. Parameters of some pulsars

PSR	T_P [msec]	*DM* [pc/cm^3]	S_{1400} [mJy]
0320+39	3032.1	26.125	2.8
0329+54	714.5	26.75	190.3
1913+16	59.029	168.77	0.8
1929+10	226.5	3.17	0.9
1937+21	1.557	71.04	16.0

The pulsar emits radiation in broad band of frequencies. The dispersion of electromagnetic waves at propagation in interstellar From high frequencies to low with speed: that the pulse of radiation drifts in receiver band Δf from high frequencies to low ones with speed:

$$\alpha_{DM} = \frac{\mathrm{d}f}{\mathrm{d}t} = f^3 \Big/ 8{,}3 \cdot 10^3 DM \, , [\mathrm{MHz/c}], \qquad (1)$$

where *f* - receiving frequency in MHz, *DM* - the dispersion measure in a parsec/cm^3 (it differs by two order for different pulsars).

For exception of dispersion influencing on duration of the registered pulse it is necessary to execute the condition $df = dt \cdot \alpha_{DM}$, where *df* – receiver bandwidth, *dt* - demanded time resolution. This condition imposes stringent restriction on bandwidth and on receiver sensitivity (realised signal-to-noise ratio - *S/N*). The common approach for *S/N* increase is usage broadband multichannel (*N* channels) receiver with total bandwidth $\Delta f_\Sigma = N \cdot \delta f$ with the conforming post processing of output signals of all channels [5-7]. It is so-called afterdetection dispersion compensators. In each channel of the receiver signals s_n (after detectors) are registered parallel in digital form- as readouts. During pulse repetition period of pulsars T_P the two-dimemsional set of readouts $s_{n,k}$, is formed, where *n* - channel number, *k* - number of readout in time. Subsequent summation of readouts in accordance with algorithm (2) with allowance with dispersion influence compensation increases *S/N* ratio in $\sqrt{N}$ times:

$$s_\Sigma(k) = \sum_{n=1}^{N} s_{n,k+\Delta n}\, , \qquad (2)$$

where Δ - conforming shift in time depending from α_{DM} .

The obtaining of considerable increase of *S/N* ratio demands application in the receiver of bank of filters with large number of channels, that, as it is known, represents a composite technical problem. The problem of formation of large number of equivalent frequency channels is effectively decided with usage of acoustooptical methods. However registration of twodimensional set of readouts $s_{n,k}$, during one pulsar period demands high speed of recording channel in digital processor [5,7].

We offer new type AO processor with additional pipeline processing of signal into the processor itself [8, 9], that allows to execute dispersion compensation in real time and more than one order reduces the requirements to productivity of an output digital processor.

3. SCHEME OF THE ACOUSTOOPTICAL PROCESSOR

The skeleton diagram of the AO processor corresponds to the scheme in fig. 1. Basically it corresponds to the schemes of AO spectrum analysers widely applicable on many radio telescopes. Radio signal $S(t)$ being subject to processing after amplification moves on acoustooptical modulator (AOM) on intermediate frequency. AOM and Fourier lens execute the Fourier transformation of input signal forming optical distribution with intensity *I*(*x, t*) in output plane. This distribution corresponds to power spectrum of processing signal $S(t)$ in sliding window with duration T_A, where T_A - temporal aperture of AOM. In customary AO spectrum analysers the distribution *I*(*x, t*) is detected and integrated by a multielement CCD photodetector. On end of given accumulation time *T* the distribution is read out by sequence of readouts from CCD and is register in

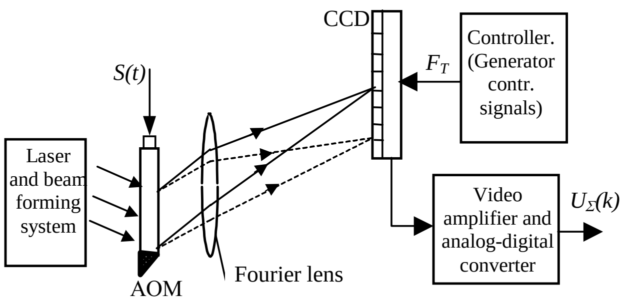

Fig. 1. The diagram of the acustooptical processor

digital processor in digital kind(form).

In our AO processor CCD works in special pipeline mode ("shift-and-add" mode). This mode is provided by special controller - generator of control signals. When control signals F_T are applied to CCD its elements are displaced by an electronic manner along the CCD aperture from one edge to other edge similarly to continuous chain (pipeline). At moving elements execute both detecting and accumulation of signals from formed frequency channels passing them one after an other, so that summation (2) is fulfilled in real time inside CCD by analogue way (in the form of charge packages) before read out signals from CCD. The running speed of CCD elements is determined by external control (frequency F_T) and can be matched to frequency drift velocity (1). Thus on CCD output the signal $U_\Sigma(k)$ is watched, which conforms envelope of pulse of radio emission from pulsar. It is compressed pulse in contrast to output signal of the broadband receiver. After amplification and analog-to-digital convertion this signal $U_\Sigma(k)$ moves to the recording system.

The offered AO processor has a number of advantages. The summation (2) descends in CCD that increases *S/N* ratio and decreases speed of reading from CCD in *N* times as contrast to known AO systems for pulsars [5]. A distinctive feature of this new type AO processor is its simple readjusting for processing signals from pulsars with different dispersion measure. The readjusting is executed by electronic way: by change of frequency F_T of control pulses. It is important to mark that due to pipeline operational mode of CCD the AO processor is invariant to time of arrival of radio emission pulses.

The AO modulator determines main specifications of AO processor, such as center frequency f_c, working bandwidth Δf, frequency resolution δf_a, number of equivalent frequency channels N. Now one-channel AOM allow to receive up to 1000-2000 resolvable spectrum points, frequency resolution - up to 40-100 kHz, band of operational frequencies - tens and hundreds megahertz. These characteristics conform the requirements shown to receivers of radio emission of pulsars.

The resolution of the acoustooptical processor on time δt_a is determined by radio emission of pulsar propagation time through band of an equivalent frequency channel δf_a:

$$\delta t_a = \delta f_a / \alpha_{DM}. \qquad (3)$$

The movement speed of charge packages along the CCD aperture is determined by frequency F_T of phase control pulses and may be changed easily. For good work of AO processor it is necessary to ensure synchronous motion of optical response from radio signal with varied frequency and CCD elements, that will be realised at control pulses frequency

$$F_T = m / \delta t_a, \qquad (4)$$

where m - number of CCD elements per one resolvable point of AO processor. In practice value of m is selected from range 2... 3. From (3) and (4) one can find

$$F_T = m \cdot 1{,}2 \cdot 10^{-4} f_c^3 \cdot DM^{-1} \cdot \delta f_a^{-1}. \qquad (5)$$

The estimations demonstrate, that for typical values of $DM, f_c, \delta f_a$ frequency F_T should vary within the limits from tens up to hundreds kilohertz, that is easily executed, as the range of CCD operational frequencies lies in limits from units of kilohertz up to units megahertz.

The authors with colleagues designed a working breadboard of AO processor. We used the helium-neon laser (P = 2 mW), AOM on the basis of TeO_2 crystal and linear CCD ILX703A (Sony), consisting from 2048 elements with size 14x14 mcm^2.

4. THE SCHEME OF AO PROCESSOR ACTUATION ON THE RADIOTELESCOPE THA-1500

In June 2001 the authors have conducted for the first time in domestic radioastronomical practice actuation of joint-stock company of the AO processor for observation of pulsars. AO processor was established in receiving complex of the radiotelescope THA-1500 (Kalyasin, Moscow region) [10], see fig. 2. The complex has two receiving channel: 610 MHz region (receiver 1) and 1,4 GHz region (receiver 2). The nominal pulsar processing system is the system on the base of filter bank having 64 frequency channels in receiver 1 [7]. The AO processor with designed additional digital part (it is shown in points region) is established in receiver 2.

Input signal of AO processor is the signal from the antenna of the radiotelescope converted to an intermediate frequency 175 MHz in front end of the receiver. The signal from AO processor output goes in multichannel integrators and after them - in a computer.

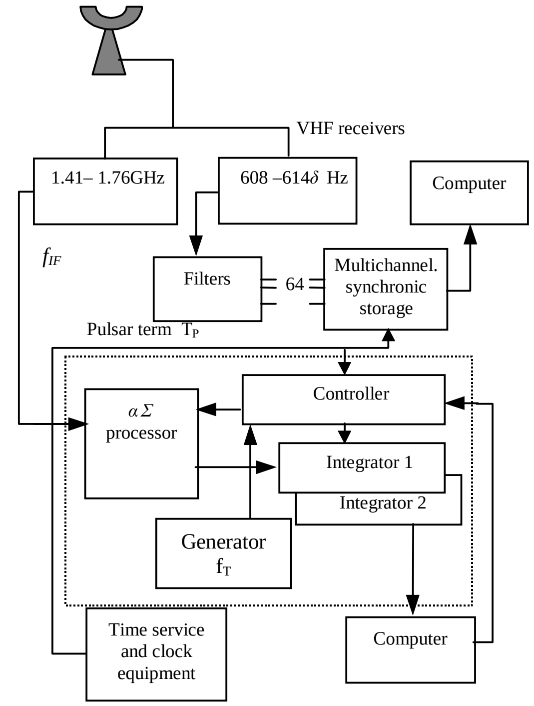

Fig. 2. A receiving complex of pulsars observation on the radiotelescope THA-1500

Each integrator contains the summator and buffer memory with a volume 4Kwords x 16bits. The work of integrators and CCD is controled by the controller. The controller is synchronised by a pulses "Pulsar period T_P". On each pulse T_P the controller provides registration with summation in the integrator of following compressed pulse on CCD output. The controller sets a time window - quantity of readouts N_C at registration of compressed pulse (N_C readouts we shall call as frame) and quantity N_K of frames summarised in the integrator. After fulfilment of given number of summations the controller relays integrators. From the earlier filled integrator the data are read out in computer and the buffer of the integrator is cleaned. The "Pulsar period T_P" in the counted instants are generated by radiotelescope Time and Clock Service equipment on base of parameters of an observed pulsar and running time of observation.

The controller allows except for pipeline operational mode of CCD to actuate a standard mode also which is used for set-up of the processor. In this case AO processor acts as multichannel AO spectrum analyser.

The full time of integration is determined by duration of period of pulses and their demanded sum necessary for signal recovery from noise. Depending on pulsar (at selected frequency and bandwidth of receiver) it is necessary to sum different quantity of pulses: for a pulsar PSR 0329+54 - about 10^2; for PSR 1937+21 - 10^5-10^6. In designed digital part the summation is distributed between integrators and computer. At first stage frames are summarized in 16-bits integrators, and then - in 32-bits words in computer memory.

5. EXPERIMENTAL RESULTS

The authors have conducted experimental researches of the AO processor characteristics both in laboratory and on the radiotelescope. Some outcomes of these researches are submitted below.

Amplitude-frequency characteristic. This characteristic determines working frequency band of the processor. She is obtained by activating of AO processor in a mode of spectrometer. The amplitude-frequency characteristic of AO processor itself is shown in fig. 3. The total amplitude-frequency characteristic with 1.4 GHz receiver front end is shown in fig. 4. In first case the –3dB level bandwidth is 90 MHz, in second case it is only 50 MHz and in this band we have 600 CCD elements (600 frequency channels).

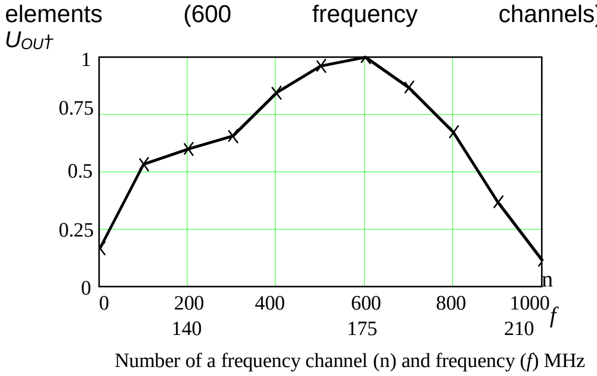

Fig. 3. Amplitude-frequency characteristic AO processor

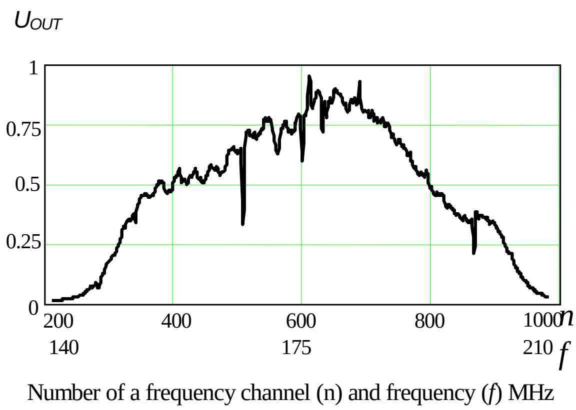

Fig. 4. Amplitude-frequency characteristic of a receiving channel with AO processor

Amplitude characteristic. The amplitude characteristic (see fig. 5) is obtained with AO processor usage in spectrometer mode also. It is measured with noise signal on receiver output (antenna is retracted from source) by signal attenuation with 2dB steps starting from saturation level at CCD output. In location of the radiotelescope an interference level rather high, therefore at measurements we sum the readouts from

100 CCD elements (that corresponds to averaging in frequency band 9 MHz) with total accumulation of readouts within 4 seconds. The characteristic demonstrates dynamic range of AO processor, it is about 30 dB.

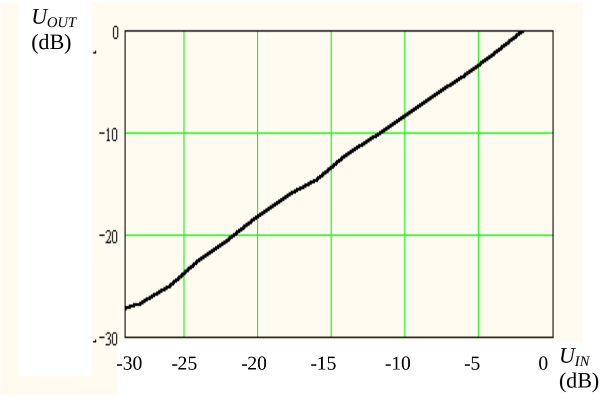

Fig. 5. Amplitude characteristic AO processor

Profiles of pulses of radio emission from pulsars. During researches the registration of pulsesof radiation of two pulsars PSR 0329+54 and PSR 1937+21 (see Tabl. 1) was conducted. In fig. 6 the profiles of pulses of PSR 0329+54 are shown. They are obtained on nominal filter bank receiver - a) and on the receiver with AO processor - b). Obtaining conditions for these profiles are different. The first profile is obtained on frequency 0,61 GHz, reception band is 6 MHz, quantity of summarized pulses is 20 with dispersion compensation (see (2)) in computer (digital form of compensation). The second profile is obtained on frequency 1.4 GHz, reception band is 50 MHz, quantity of summarized pulses is 20 with dispersion compensation in real time during signal accumulation into CCD (analogue form of compensation). On frequency 1,4 GHz the source flux is much less and noise level is more high than on frequency 0,61 GHz, so it has demanded respective increase of number of summarized pulses.

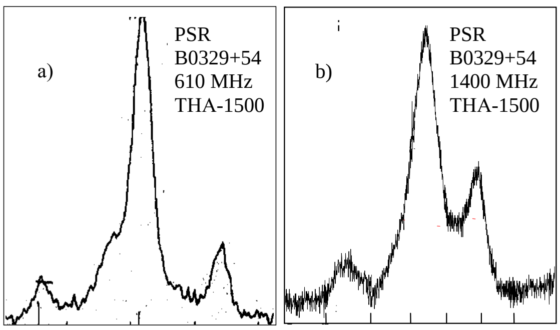

Fig. 6. Profiles of pulses of pulsar 0329+54, obtained on the radiotelescope THA-1500: a) - with nominal filter bank receiver and b) - with the acoustooptical processor

Thus conducted in laboratory and real radiotelescope conditions researches have shown possibility of AO processor usage for processing pulses of radio emission from pulsars. By electronic readjustment the AO processor can be adjusted on processing of radio emission from pulsars with different dispersion measure.

We hope that this type AO processor can be used for routine pulsar observation on different scintific programms including timing of millisecond pulsarsthuch as PSR PSR 1937+21.

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