AN ACOUSTO-OPTICAL IMAGE PROCESSOR AND ITS APPLICATION TO A 160 MHz INTERFEROMETER

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ABSTRACT

Radio emissions from the Sun are characterized by extremely rapid time variation. Although they are relatively strong, the signal to noise ratio becomes critical when we observe them with high resolution in space and time. To improve the S-N ratio, we have investigated the feasibility of an acousto-optical processing of interferometer images and applied it to the 160 MHz interferometer of the Nobeyama Solar Radio Observatory. We present here results of simulation experiments and preliminary solar observations with the new image processor.

I. INTRODUCTION

A 160 MHz interferometer of a compound type has been put in operation since 1970 at Nobeyama to investigate fine structure of radio emissions from the Sun (Takakura et al., 1967). The interferometer scans 64 min of arc centred at the Sun in the E-W direction at a rate of 10 Hz to follow rapid time variations. The scanning of the fan beam across the Sun is performed by a phase-controlled local oscillator system. The signal of a variable frequency (f_c) oscillator (VFO) is transmitted from one end of the array via each antenna to the other end of the array where the signal is mixed with the signal of an another oscillator of a fixed frequency (f_o). The converted signal of the frequency of ($f_o - f_c$) is transmitted back via each antenna. Under each antenna these two signals are mixed to produce the fixed frequency (f_o) signal which is fed to the mixer of the pre-amplifier as the local source. The phase of the local signal changes with the frequency of the VFO. The amount of the phase change is proportional to the distance of an antenna in question from the antenna at the east end.

The beam scanning system has a disadvantage as to S-N ratio. Signals which come from a region of the sky are missed unless the beam is directed there. Let θ be the angular extent (in one dimension) of the field of view of an interferometer and $\Delta\theta$ the width of the fan beam.

C. van Schooneveld (ed.), Image Formation from Coherence Functions in Astronomy, 165-172.

Then, the S-N ratio for the interferometer would be deteriorated by a factor of $(\theta/\Delta\theta)^{1/2}$ for such a beam scanning system as described above than for a system of multi-beams which wholly cover the field of view. The S-N ratio of the 160 MHz is not good enough for weak bursts to see fine structures in 0.1s resolution. To improve the S-N ratio we have planned to modify the image processor either to a multi-channel (∿ 50 in the present case), a correlator mode or an acousto-optical processor. For some reasons we have chosen the last system for the image processor of the 160 MHz interferometer.

An acousto-optical processor for a radar array was first suggested by Lambert et al. (1965). The application of such a system to the Culgoora radioheliograph was proposed subsequently by McLean et al.(1967). However, eventually 48 multi-beams which scan the Sun in the E-W direction were constructed for the radioheliograph image processor. The principle of an acousto-optical processor is briefly given below (for detailed descriptions, see Lambert et al. (1965) and Cole (1965)). A RF signal is applied to a transducer attached on the top of an acousto-optical medium. The transducer converts the RF signal to the acoustic wave which travels through the medium and damps into an absorber at the bottom of the medium. The refractive index of the medium varies periodically as the acoustic wave travels. If a light beam is applied to the medium with a large angle to the direction of the wave propagation, part of the light beam is diffracted and focused on the image plane. The intensity of the diffracted light is proportional to the power of the applied RF signal, and the phase relative to that of the RF signal is maintained. Therefore, when coherent RF signals are applied to two separate acousto-optical modulators (Ao), the light diffracted through one of the AOs can interfere with that diffracted through the other. If signals from two separate antennas which are directed to the sky are applied to the two separate AOs, the image of the interference pattern is just the Fourier component of the sky which the two antenna interferometer would give. Any different signals which come from different directions produce independent diffracted images simultaneously. Consequently the S-N ratio is improved by a factor of $(\theta/\Delta\theta)^{1/2}$ than that of an interferometer of a conventional beam scanning type. In the present case, $\theta = 64'$ and $\Delta\theta = 2'$ so that $(\theta/\Delta\theta)^{1/2} = 5.7$

We have made fundamental experiments on an acousto-optical image processor since 1975 with a special application to an interferometer in mind. In this report we present results of the experiments and preliminary observations of solar bursts recorded with this new image processor.

2. ACOUSTO-OPTICAL IMAGE PROCESSOR FOR THE 160 MHZ INTERFEROMETER

The antenna arrangement of the 160 MHz interferometer is illustrated in Figure 1. Signals from 8 short-spacing antennas are multiplied by those from 3 long-spacing antennas to form a sharp fan-beam of approximately 2 min of arc in the E-W direction. Eleven AOs, each of which

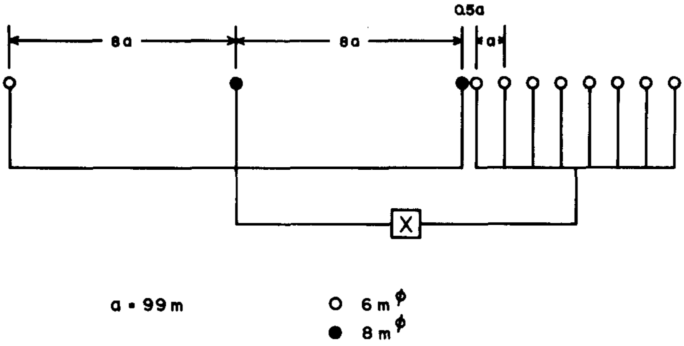

Figure 1. The antenna arrangement of the 160 MHz interferometer at Nobeyama.

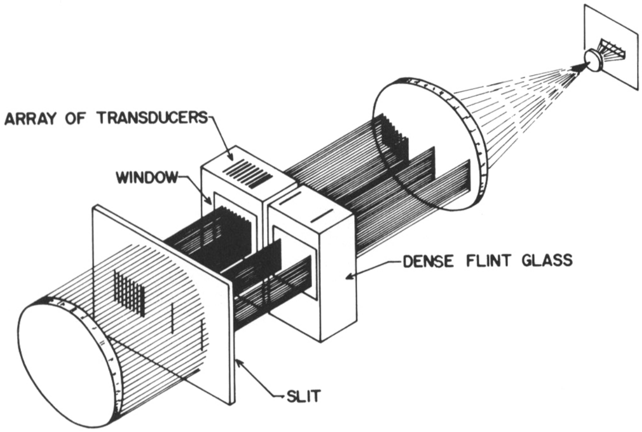

Figure 2. Acousto-optical light modulators and an array of slits placed in front of the modulators.

is to be connected with the corresponding antenna, are arranged to form an array analogous to the antenna array in a reduced scale. The fundamental spacing of the AO array is 4 mm. To keep the spacings very accurately an array of slits (width and length are 0.5 and 2.0 mm res-

Table 1. Specification of Acousto-optical Modulators

centre frequency	37 MHz
band width	± 5 MHz
transducers	$L_{i}N_{b}O_3$ (2 x 14 mm^2)
medium	dense flint glass
sound velocity	3720 m/s
deflection efficiency	30 % max

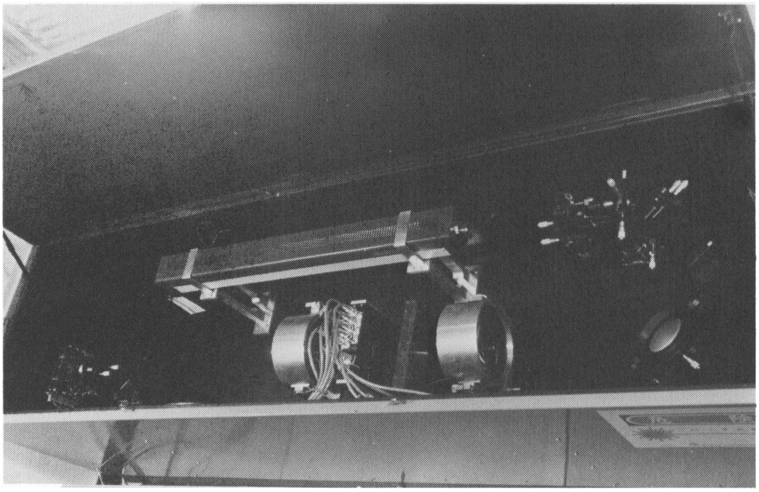

Figure 3. A photograph of the acousto-optical image processor to illustrate the arrangement of components.
A He-Ne laser, a beam expander, a mirror (top : left to right), a mirror, a collimating lens, an array of slits, acousto-optical modulaters, a focusing lens, an expanding lens and a 256 photo-diode array (bottom : right to left).

pectively) is placed in front of the modulators (see Figure 2). Physical parameters of the AO are shown in Table 1. A 15 mW He-Ne laser is used as a light source. The beam is expanded by a combination of a microscope lens and a pin hole and then collimated by a 15 cm ϕ lens (f = 700 mm). The collimated light is diffracted by the AOs and focused by a 15 cm ϕ lens (f = 700 mm). The first-order diffracted light only is expanded to form an image on a 256 photo-diode array (Figure 3). The optical components including the AO's are set on an optical bench in a dark box. Two tire-tubes support the optical bench to isolate it from disturbances from floor. Tire-tubes are proved to be good absorbers of vibrations over a wide frequency range.

RF signals are amplified and converted to 15 MHz under individual antennas and transmitted to the observing room. IF signals are again

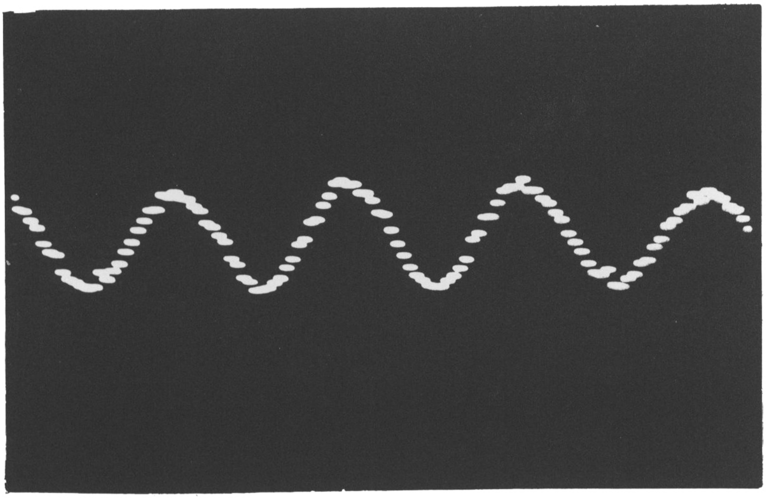

Figure 4 (a)

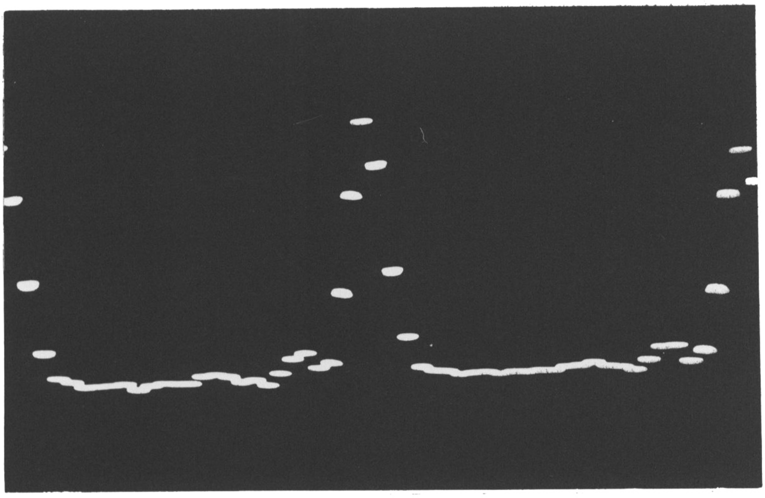

Figure 4 (b)

Figures 4 (a) and (b). Interference patterns due to adjacent two modulators (a) and eight modulators of short-spacing (b). Signals from SG are applied to modulators through power amplifiers. Different scales are used in (a) and (b).

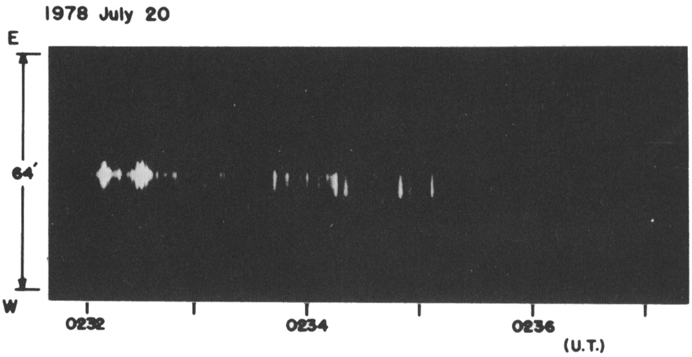

Figure 5. An example of the east-west distribution of solar bursts recorded with the acousto-optical image processor.

converted to 37.4 MHz and applied through power amplifiers to the transducers. The phase of signal from long-spacing antenna is changed by 0 and 180 degrees alternately in order to perform the multiplication of signals from long-spacing antennas with those from short-spacing antennas. In the first cycle when the two signals are added in phase, the charge accumulated in the photo-diode array is picked up sequentially and stored in an analogue memory. In the next cycle when the two signals are subtracted, both the signal from the photo-diode array and the signal stored in the memory are fed synchronously to a differential amplifier to get the signal resulted from the multiplication. A computer processing would be more accurate. However, since two small computers are almost fully occupied to control various kinds of equipments, to process images of a 17 GHz interferometer of a correlator-type in real time and so on, there is no extra ability left to make further processings. Only the output of the differential amplifier is stored in magnetic tapes.

3. RESULT

Simulated patterns are shown in Figures 4(a) and (b) for 2 and 8 element interferometers respectively. Signals are fed to two adjacent modulators (a) and to eight modulators of the fundamental spacing (b) directly through power amplifiers. Sensitivities of individual photo diodes have not been calibrated there. The accuracy of the sensitivity is approximately 5%.

Solar bursts were observed tentatively with the 8 element grating interferometer of short-spacing antennas. Part of the records is shown in Figure 5. The output of the photodiode array was displayed on CRT and photographed on a film which moves continuously. The result as shown above is only preliminary. Observations of the Sun with the compound system will work soon.

As far as the present system works well, it is not difficult to extend the single frequency observation (say, 160 MHz in the present case) to a simultaneous multi-frequency observation. When two signals of different frequencies are applied to the modulators simultaneously, two diffracted images form on two separate horizontal lines. Therefore, with the use of an area array or two different arrays of photo diodes in parallel we would obtain brightness distributions of the Sun at two frequencies simultaneously.

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REFERENCES

Cole, R. W., 1965, Optics Technology, 1, p. 31.

Lambert, L. B., Arm, M. and Aimette, A., 1965, in "Optical and Electro-optical Information Processing", ed. Tippet et al., MIT press., p. 715.

McLean, D. J., Lambert, L. B., Arm, M. and Stark, H., 1967, Proc. I. R. E. E., Australia, 28, p. 375.

Takakura, T., Tsuchiya, A., Morimoto, M. and Kai, K., 1967, Proc. Astron. Soc. Australia, 1, p. 56.

DISCUSSION

Comment M.S. EWING
If you were to use a cylindrical transform lens, you would have an output plane having a spectrum in one direction and fringe-rate spectrum in the other direction. This would concentrate the laser power into one or a few fringe rate cells (at least for a 2-element interferometer). Thus less laser power might be required.

Reply M. MORIMOTO
Because of the large distance (typically 5 mm or 10^4 λ) between the piezo-transducers fringe separation tends to get too small. Thus the problem is how to expand the beam in the fringe axis rather than concentrating it.

Comment T.W. COLE
Do you make your own modulators and is it a problem to obtain modulators made to your own specifications at a non-infinite price?

Reply M. MORIMOTO
As I mentioned the modulator was made under a generous cooperation of the Matsushita Research Insitute Inc. However, the accuracy of the modulator geometry is determined by the slits in front rather than by the setting accuracy of the transducers. Thus it does not absorb costs of an infinite amount.