Proceedings of the Research Institute of Atmospherics,
Nagoya University, vol. 26 (1979)

A PROJECT TO IMPROVE THE SENSITIVITY AND THE PHASE STABILITY OF THE λ 8-CM RADIOHELIOGRAPH AT TOYOKAWA

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1. Introduction

The λ 8-cm radioheliograph at Toyokawa has been in operation since 1975 (Ishiguro et al., 1975). Daily solar radio maps are obtained in conjunction with the λ 3-cm radioheliograph (Tanaka et al., 1970) to study the structure of the solar atmosphere between the base of the corona and the chromosphere, coronal holes, S-components emitted from active regions, and radio bursts (Shibasaki et al., 1976, 1978).

The antenna system is a T-shaped array of 3-mϕ antennas, 32+2 elements on the East-West baseline, 16+1 elements on the North-South baseline, and can be operated as one-dimensional interferometer arrays or two-dimensional T-shaped array. In the present system, microwave signals received by 3-mϕ antennas are transmitted to a remote front-end receiver via a branching network of waveguides (Tanaka et al., 1969). Each transmission line from an antenna is equipped with a rotary phase shifter to sweep a fan beam or a pencil beam. As the mapping of the Sun is performed by scanning, and that it is mechanical, radio maps thus obtained are useful as far as the stationary features in the maps are concerned, but the studies of time-variable phenomena such as radio bursts requiring a sufficient time resolution are considerably limited.

On the other hand, the study of low-contrast features such as coronal holes and dark filaments is limited by the dynamic range of a radioheliograph. The dynamic range of a radioheliograph is governed mainly by the sensitivity and the sidelobe level. As a scanning system can assign less integration time to each picture point than a multi-beam system, it is obvious that the former is less sensitive than the latter. It is remarkable especially in a radioheliograph with a high spatial resolution. In addition, the transmission loss in the present waveguide network amounts to 4 dB and this contributes to considerable reduction in sensitivity.

Phase errors originating in signal transmission from each antenna to a remote front-end receiver have dominant effect on the sidelobe level. The present waveguide network is exposed to the open air, so that the phase stability of the system is affected by the non-uniform variation of the ambient temperature along the array. If the phase errors are known accurately from the calibration observation they can be corrected through data processing (Suzuki, 1977). Even if the phase errors are not known in advance, an uniform array has the advantage of making use of the redundancy in the possible antenna pairs to correct for the phase errors to a certain extent (Jennison, 1958; Ishiguro, 1971, 1974; McLean, 1973; Nakajima, 1979). To apply this concept effectively, correlations between all the possible antenna pairs must be measured simultaneously. The same technique can be used for calibrating gain errors. Although the effect of gain errors is less sensitive to the sidelobe level than that of phase errors, it is required to minimize gain errors to improve the dynamic range as wide as possible.

Considering the above-mentioned disadvantages in the present system, it has been proposed to extend the system to a correlator array. In 1978, as the first step to this extension, a project was initiated to improve the sensitivity and the phase stability of the present system by replacing the waveguide network with a combination of low-noise, phase stable front-ends, and low-loss, phase stable coaxial cables to transmit signals from and to the front-ends. A brief explanation on the proposed system is presented.

2. The outline of the proposed system

Figure 1 shows the block diagram of the proposed system. At the present time, the total number of antennas is 51, but another antenna is scheduled to be set on the North-South baseline to form a compound-interferometer array. Rotary phase shifters are left as they were and are used as a temporary expedient until it is confirmed that the scanning by digital phase shifters equipped at the second IF stage

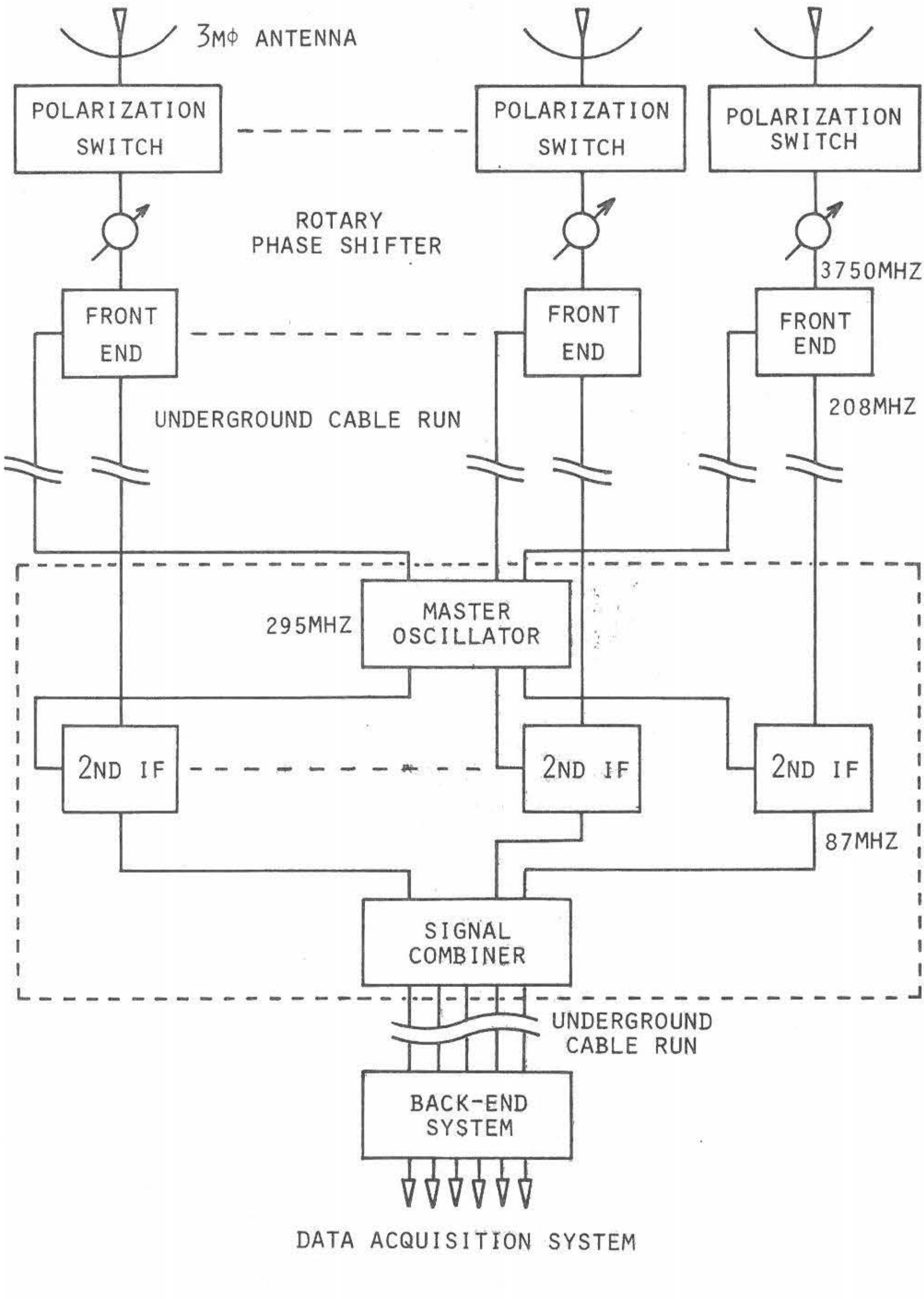

Fig. 1. Block diagram of the proposed system.

works satisfactorily.

A front-end consists of a Dicke switch, a low-noise FET amplifier, a mixer-preamplifier, and a phase-locked oscillator (PLO). The size of the front-end is so compact that two front-ends can be put together in a small temperature-controlled box to share a PLO for common use. The temperature inside the front-end box must be kept within 0.1°C accuracy to achieve the required phase stability. In the near future, low-noise FET amplifiers will be moved to the positions close to the polarization switches to reduce the system noise temperature as low as possible. In the present design, the system noise temperature is expected to be about 1000 K that is comparable to the antenna temperature by the quiet Sun.

The PLO's are locked to the reference signals of 295 MHz distributed from a common master oscillator. A preliminary study to achieve the expected phase stability of the new local oscillator system was finished (Naito, 1979). The study suggests that it is not so difficult to attain the phase stability of 5° rms for a month using ordinary components in the market. Relative phase stability between the two PLO's locked to a common reference signal was measured, and the effects of the changes in the ambient temperature, DC supply voltages, and the reference-signal level were investigated. It was made clear that the instabilities in the stage of harmonic generation have predominant effect on the phase error, and it is recommended to use a higher frequency as a reference signal. The output level of a master oscillator will be controlled within a few percent by an ALC loop to improve the stability.

The stability of the electrical length of transmission lines is also an important factor which affects the total phase stability. It goes without saying that a careful attention should be given to the reference-signal cables rather than the IF return cables. We decided to use a foamed-polyethylene coaxial cable as the transmission line, because it is low-loss and has good phase stability and yet is inexpensive. The phase stability of a coaxial cable is determined by the net effects of the change in the dielectric constant of the insulator and the thermal expansion of conductors. The temperature coefficient of the dielectric constant of polyethylene is negative and one order of magnitude greater than the positive coefficient of the thermal expansion , the temperature coefficient of the electrical length can be reduced considerably.

It was made clear from the measurement (Naito, 1979) that the foamed-polyethylene coaxial cable meets the requirement and has the stability of about 6 X 10^{-6}/°C. If the cables are buried at the depth of 1.5 m below the ground level, where the temperature variation is expected to be less than 0.1°C/day, change in the electrical length of a 100 m cable is only 0.06 mm/day which corresponds to the phase error of 0.3°/day at 3750 MHz and can be neglected at the first IF frequency (208 MHz). The length of each IF return cable from the front-end is adjusted so that the zero delay error is obtained near 0° declination.

At the second IF stage, transmission loss and front-end gain for each channel are equalized. Phase errors are adjusted by 8-bit digital phase shifters inserted in the lines of the second local oscillator signals. These phase shifters are computer-controllable and will offer more flexible modes of scanning than the present rotary phase shifters. The signal combiner does the same function as the waveguide network. Operational modes of the radioheliograph can be changed as in the present system (Ishiguro et al., 1975). In addition, any combination of antennas can be formed to calibrate gain and phase or to check the system operation. Each channel can be operated as an independent radiometer, so that the calibration of total errors in gain and phase will be done more efficiently than the present system.

This work is supported by Scientific Research Grant of Ministry of Education (342004).

References

Ishiguro, M.: Image Correction in High-Resolution Radio Interferometer, proc. Res. Inst. Atmospherics, Nagoya Univ., 18, 73 (1971).

Ishiguro, M.: Phase Error Correction in Multi-Element Radio Interferometer by Data Processing, Astron. and Astrophys. Suppl., 15, 431 (1974).

Ishiguro, M., Tanaka, H., Enome, S., Torii, C., Tsukiji, Y., Kobayashi, S. and Yoshimi, N.: 8-cm Radioheliograph, Proc. Res. Inst. Atmospherics, Nagoya Univ., 22, 1 (1975).

Jennison, R. C.: A Phase Sensitive Interferometer Technique for the Measurement of the Fourier Transform of Spatial Brightness Distribution of Small Angular Extent, Mon. Not. R. Astron. Soc., 118, 276 (1958).

McLean, D. J.: A Proposed Millimeter Radioheliograph, Proc. IEEE, 61, 1318 (1973).

Naito, Y.: Phase Stability of the New Local Oscillator System of the λ 8-cm Radioheliograph at Toyokawa, Proc. Res. Inst. Atmospherics, Nagoya Univ., 26, in this issue (1979).

Nakajima, H.: private communication (1979).

Shibasaki, L., Ishiguro, M., Enome, S., Tanaka, H., Torii, C., Tsukiji, y., Kobayashi, S. and Yoshimi, N.: λ 8 cm Radioheliograms, Proc. Res. Inst. Atmospherics, Nagoya Univ., 23, 21 (1976).

Shibasaki, K., Ishiguro, M., Enome, S. and Tanaka, H.: A Coronal Hole Observed with a λ 8-cm Radioheliograph, Publ. Astron. Soc. Japan, 30, 589 (1978).

Suzuki, N.: Phase Error Measurement and Correction in 8-cm Radioheliograph, Proc. Res. Inst. Atmospherics, Nagoya Univ., 24, 13 (1977).

Tanaka, H., Kakinuma, T., Enome, S., Torii, C., Tsukiji, Y. and Kobayashi, S.: A High-Resolution Quick-Scan Interferometer for Solar Studies at 3.75 GHz, ibid, 16, 113 (1969).

Tanaka, H., Enome, S., Torii, C., Tsukiji, Y., Kobayashi, S., Ishiguro, M. and Arisawa, M.: 3-cm Radioheliograph, ibid, 17, 57 (1970).