ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S10TS08

An Optical Fiber Phase Lock Network of a Radio Interferometer

Masanori Nishio, Susumu Kawashima, Chikayoshi Torii, Hiroshi Nakajima
Nobeyama Radio Observatory, National Astronomical Observatory
Nobayama, Minamisaku, Nagano, 384-13 Japan

Toshio Takabayashi, Katsuhiko Nishikawa, Norio Futagawa
Space and Laser Communication Development Division, NEC Corporation
Ikebe 4035, Midori-ku, Yakohama, 226 Japan
and
Shigeru Tanaka
Sumitomo Electric Industries Ltd. Yokohama Laboratory
Taya 1, Sakae-ku, Yakohama, 224 Japan

Abstract

A new phase-lock network using fiber-optic system was developed as a local signal distribution system for 84 antennas of the Nobeyama Radioheliograph. This network is a open loop system and consists of a master oscillator with an E/O converter, a 1-to-84 optical divider, phase stable optical fiber cables and phase stable phase-locked oscillators with O/E converters. Phase stability of the network and phase noise generated at the O/E converter are discussed. This phase-lock network insures the required phase stability of 3deg/6hours. The phase noise increases the coherent loss of 0.1% at the correlator output, which is very low. This is the first large application of fiber optic devices to an open loop phase-lock network. Our system is very simple and phase-stable. Therefore, it is suitable to the connected array with large number of antennas.

1 Introduction

RF signal transmission systems using optical fibers have advantages of low loss, wide bandwidth and high durability to electro-magnetic interferences. These characteristics are beneficial to long-distance signal transmission. Furthermore, development of a specific optical fiber extended applications of the fiber-optic system to precise timing signal transmission and phase-lock link [1]. At the JPL, a fiber-optic system was tested to distribute a reference frequency to a Deep Space Station, which usually employed coaxial cables [2]. In a VLBI system of the National Astronomical Observatory, Japan, the fiber-optic system is installed to transmit a frequency standard signal from a hydrogen master to a remote antenna. The phase stability was about 55 times better than ordinary coaxial cable transmission systems [3]. At the National Laboratory for High Energy Physics, Japan, a part of coaxial cable link between the 2.5GeV LINAC gun room and the TRISTAN control room was replaced by a fiber-optic system [1]. Another approach using an active phase stabilizer was also developed at the JPL, and it compensated the delay variations using signals reflected at remote units [4]. At the CSIRO, an optical fiber network is installed to the Australia Telescope. This telescope is a radio interferometer with 5+1 paraboloidal antennas of 22-m diameter and a closed loop network with active phase stabilizer is used to lock the phase of local oscillators.

In the radio interferometer, precise measurements of phase among received signals are quite essential to synthesize high-quality images. Although the closed loop phase-lock network is quite stable, its configuration is complicated. As the open loop network has a simple structure, it is suitable for the interferometer with large number of antennas. At the Nobeyama Radio Observatory, a new radioheliograph is now under construction [5]. This system is a radio interferometer for solar observations, which consists of 84 small paraboloidal antennas of 80-cm diameter. These antennas are aligned on a T-shaped baseline of 490m east-west and 220m north-south. In this system, an open loop phase-lock network is installed to synchronize local oscillators. This is the first large application of fiber optic devices to an open loop phase-lock network. The phase stability of the open loop network is sensitive to the phase responses of the devices in the network. In addition, noises generated by the optical devices in the network increase phase noises of local oscillator outputs and degrade the sensitivity of the interferometer. Therefore, we have analyzed the phase stability and the phase noise of this network.

In this paper, we describe the outline of the developed optical fiber phase-lock network and discuss the phase stability and the phase noise of this network.

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2 Outline of the Phase-Lock Network

The Nobeyama Radioheliograph operates at 17GHz. Signals received by the antennas are amplified and frequency-converted to IF signals of 200MHz, and transmitted to a observation building. Then, cross-correlations of the received signals are measured for all antenna pairs to obtain Fourier components of radio images. Figure 1 is a function block diagram of the receiver. Low-noise amplifiers, frequency down-converters and local oscillators are installed in front-end boxes of antenna sites. Each antenna and the observation building are linked through optical fiber cables. The IF signals are transmitted to the observation building via these optical fiber cables. Local signals of frequency down-converters are phase-locked to a reference frequency of 525MHz transmitted from a master oscillator in the observation building through the optical fiber cables. An output of the master oscillator is converted to an optical signal, which is splitted to 84 blanches by optical dividers and transmitted to 84 antennas. The modulated optical signals are demodulated by O/E converters in the front-end boxes. Phase-locked oscillators (PLO's) are used to generate local signals, which are phase-locked to the reference signals.

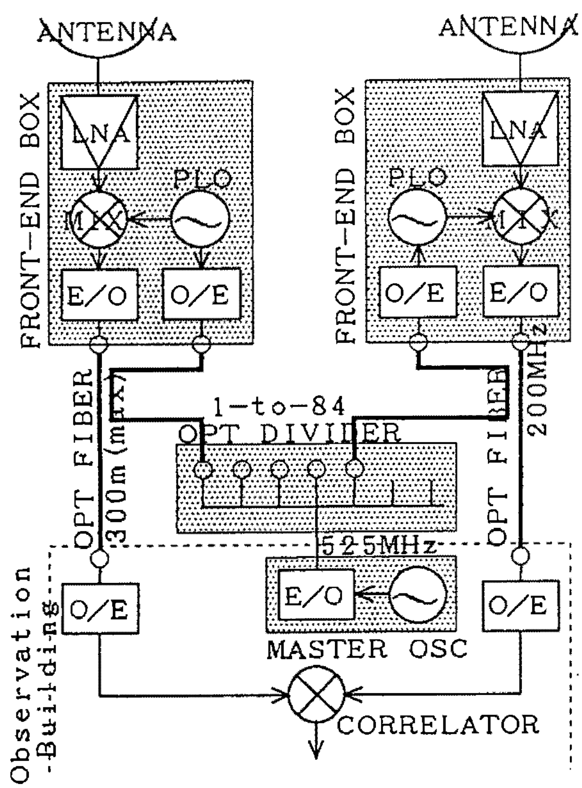

Figure 1: Functional Block Diagram of the Radioheliograph Receiver.

Each PLO of the Radioheliograph consists of a 8.4GHz variable frequency oscillator (VCO), a 1/16 frequency divider, a phase-detector (PD), a low-pass filter and O/E converter. Figure 2 is a block diagram of the PLO. Since the frequency down-conversion to the received signals at 17GHz is performed by a harmonic mixer, the second harmonic frequency of the PLO output is used as the local signal.

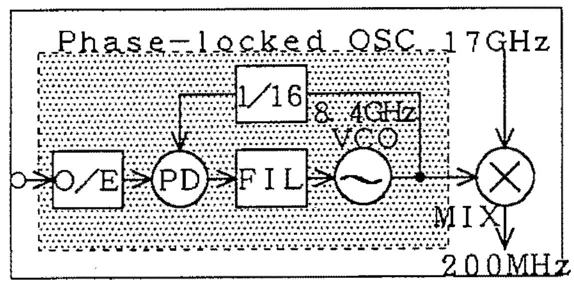

Figure 2: Block Diagram of the PLO.

3 Phase Stability of the Network

As mentioned above, the phase-lock network is an open loop system and phase drifts of the network arise from following origins;

(1) temperature responses of the optical fibers,
(2) responses to mechanical stress of the optical fibers,
(3) temperature responses of PLO's,
(4) responses to input power drifts of PLO's, and
(5) responses to supply voltage drifts of PLO's.

Phase drifts caused by (4) and (5) are relatively small.

The temperature coefficient of the phase stable optical fiber cable is less than 1.5ppm/C (5ps/km/C). The cables are buried 1.2m depth in the ground, where the temperature variations are less than 0.1C/day. As a result, phase drifts of 17GHz RF signals are less than 1 deg/day for the cables of 300m length.

Optical fibers are also used to transmit the local reference signal across azimuth and elevation axes from antenna bases to the PLO's in the front-end boxes behind main reflectors. Fibers are bent and twisted according to tracking motions of antennas, with the minimum bending radius of 3 cm. These mechanical stresses cause phase variations of transmitted RF signals. When the cable is bent from the straight line, the phase of RF signals increases according to decrease of the bending radius. Figure 3 shows the relation of the phase changes of RF signals and the bending radius of the cable. Phase change of RF signals at 17GHz is about 10deg when the cable is bent from the straight line to the radius of 3cm. As the cable is loosely bound at the axes to avoid such a strong stress in case of the Radioheliograph, the actual phase variations are much smaller.

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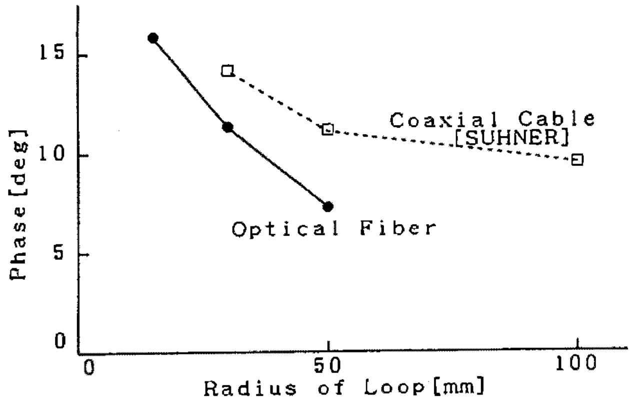

Figure 3: Relation of the Phase of RF Signals and the Bending Radius.

Phase characteristics of the devices in the PLO are sensitive to temperature variations. In the Radioheliograph, these devices are placed on a thermally stable base controlled by a Peltier device. The phase deviations of the temperature stabilized PLO due to ambient temperature variations are 0.5deg/C at 8.4GHz as shown in Figure 4. The PLO is mounted in the front-end box which is maintained at temperature of 40±0.5C.

Phase and gain error in the measured Fourier components cause a reduction in gain of the synthesized beam and an increase in its sidelobe level. Total Phase stability required to the Radioheliograph is less than 3deg during observation time of 6hours. This requirement is sufficiently satisfied in the phase-lock network of the Radioheliograph.

4 Phase Noise of the Network

The phase noise of the PLO degrades the sensitivity of the radio interferometer. The degradation of sensitivity is evaluated as the coherent loss of correlation output [6]. Usually, the phase noises of the master oscillator and the VCO are main origins of the PLO phase noises. In the new phase-lock network, the additional phase noise is generated in the O/E converter of the PLO. The phase noise level is explained by using the carrier-to-noise ratio (C/N ratio). The output RF signal power of O/E converter is shown by $P_s=\eta e P^2 R_L/2h\nu$, where P is the optical input power, η is the quantum efficiency of photo diode, e is the charge of an electron, R_L is the output load register, h is the Plank's constant, ν is the light frequency. In the phase-lock network of the new radioheliograph, the optical input power is about -25dBm including the transmission loss of both the optical divider and the optical fiber cables. The wavelength of light is 1.3μm. The output load register is 2.8kΩ. Therefore, the detected RF signal power is calculated to be 7.9x10^{-9}W, where we assume the quantum efficienc of photo diode η is 60%. The output noise power of the O/E converter is estimated to be about 1.7x10^{-20}W/Hz, which is limited by the thermal noise of the output load register in case of the PIN photo diode. The C/N ratio derived from the above values is -116dB/Hz. On the other hand, the measured value of the C/N ratio was about 101dB/Hz at 10kHz offset point from carrier when the optical input power was -25dBm. The measured ratio is deteriorated by 15dB compared with the calculated one, which is probably caused both by the noise included in the master oscillator output itself and by inadequate matching between the photo diode and the transducer amplifier. Assuming the cut-off frequency of the PLO loop filter is 50KHz, this experimental result corresponds to the additional coherent loss of less than 0.1%.

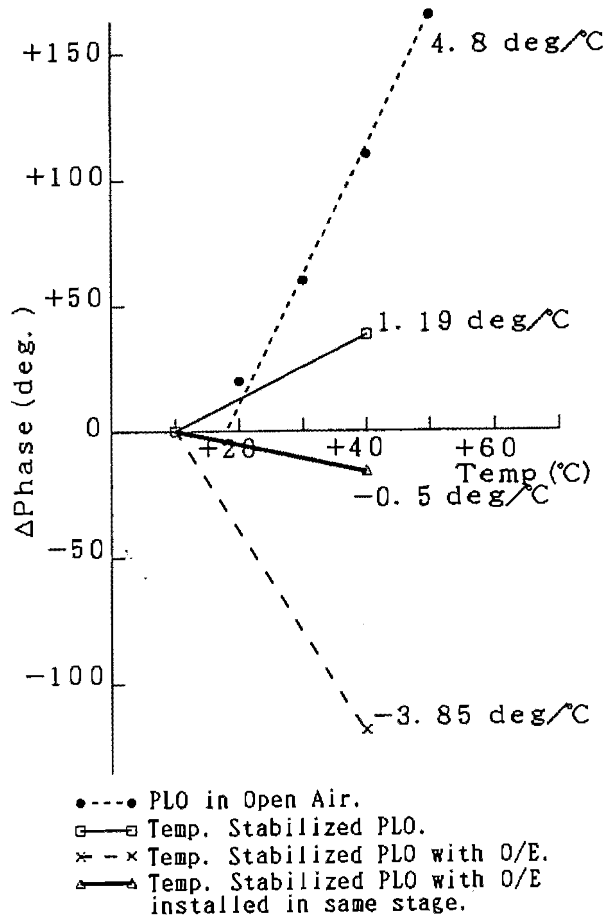

Figure 4: Realtion of the Phase of PLO Outputs and the Ambient Temperature.

5 Summary

An optical fiber phase-lock network is installed to the Nobeyama Radioheliograph. This network is a open loop system and its phase stability strongly depends on re-

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sponses to temperature and mechanical stress of the optical fiber cables and response to temperature of the PLO's. The network satisfies the phase stability of 3deg/6hours in rms, which is required in the Nobeyama Radioheliograph. The phase noise generated at the O/E converters causes the coherent loss of 0.1% at the correlator output.

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