Proc. International Conference on Space Optical Systems and Applications (ICSOS) 2014, P-21, Kobe, Japan, May 7-9 (2014)

Optically controlled beam former using phased array laser

Eisuke Haraguchi*, Junya Nishioka, Jiro Suzuki, Toshiyuki Ando
Information Technology R&D Center
Mitsubishi Electric Corporation
5-1-1 Ofuna Kamakura, Kanagawa 247-8501, Japan
Eisuke.Haraguchi@cw.MitsubishiElectric.co.jp

***Abstract*—Optically controlled beam forming techniques are promising candidate to realize a large scale phased array antenna system. In this paper, we study the optical phase locking of multiple optical beams to apply optically beam former for receiving phased array antenna. We demonstrated in the bench top experiment of three beams system, each optical signal phase has been stabilized with relative phase error less than 0.2 degrees.**

Keywords—optical phase lock, optical beam former, heterodyne detection

I. Introduction

Recently phased array beam forming techniques has been attractive attention for advanced wireless communications, such as the next-generation satellite communications, mobile radio communications, and wireless local area networks because of its flexible beam control. As increasing communication capacity, the required number of antenna elements increases and the carrier frequency becomes higher; however, it inevitably increases the equipment weight, the feeder losses, and complexity of circuitry. Optically controlled beam former is promising candidate to realize such a large scale phased array antenna system because of its wide bandwidth, a light-weight and no electromagnetic immunity (EMI)[1]-[3]. Many authors reported optically controlled beam-shaping, beam-scanning and multi-beam transmitting array antenna, however, very few papers discussed the receiving mode for array antenna because of difficulty to maintain receiving antenna distribution[4][5]. In order to realize optically controlled beam former for array antenna in receiving mode, it is necessary to maintain relative phase of receiving signals among adjacent antenna elements under changing of each optical pass length by environmental vibration as well as variation of temperature.

In this paper, we demonstrated on the optical phase locking of three optical beams to apply optically beam former for receiving phased array antenna. In the present systems residual phase error signals were fed to optical frequency shifters as optical voltage controlled oscillators, leading to realize of endless phase control for each element beam.

II. Experimental Setup

The experimental setup for the optical phase locking of three optical signals to apply optical beam former is shown in Fig.1. The master oscillator laser (MO-Laser) is a single polarization fiber laser with wavelength of 1550 nm and line width of 100 kHz. The output beam from MO-Laser is preamplified to 200 mW and divided into three signal beams and a local beam. Signal beams are coupled to optical frequency shifter (OFS) and phase modulator (PM). Here, the OFS roles as an optical voltage controlled oscillator for phase control. When the PLL is locked, the average frequency of the OFS exactly equal to the average frequency in the RF master oscillator of 110 MHz. The PM operates the two tone RF signals. Two tone signal consists of the 3 GHz (fr) signals which is simulated receiving phased array antenna and the unique frequency with a small (< 0.1 degrees) phase dither to discriminate the heterodyne signal of each beams[6]. In order to discriminate the three optical signals, each PM is operated at different frequencies of 40 MHz (f1), 60 MHz (f2) and 100 MHz (f3). The signal beam from each PM are collimate with 1 mm in diameter, and the distance between adjacent signal beams is about 1.2 mm. Then the signal beams are sampled by the beam splitter (BS1) and the reflected beams are combined with a local beam (Local) using a beam splitter (BS2). The other output signal beams from BS1 are coupled to far field pattern monitor(IR Camera) and photodiode2. The output from BS2 are coupled to a photodiode. The optical heterodyne signal of a photodiode consists of a carrier and three side carriers with different frequencies. In frequency discrimination circuit, a single side carrier is extracted from optical heterodyne signals, then converted to the same frequency as an RF master oscillator. The output signals from frequency discrimination circuit are followed to the PLL circuit to detect the phase error and to feedback to each OFS. The PLL circuits consist of a phase frequency detector (PFD), a loop filter (LF) and a voltage control oscillator (VCO). The PFD compares the phase and frequency of the output signal from frequency discrimination circuits to the RF master oscillator signal. The phase error signals are filtered by the LF, then applied to the VCOs. The LF has its bandwidth of more than 10 kHz. And the output signals of the VCO are applied to the OFSs. Each signal beams is locked to the RF master oscillator under closed loop condition. In order to verify the phase locking status, output signals from PLL circuit are split and measured using a network analyzer.

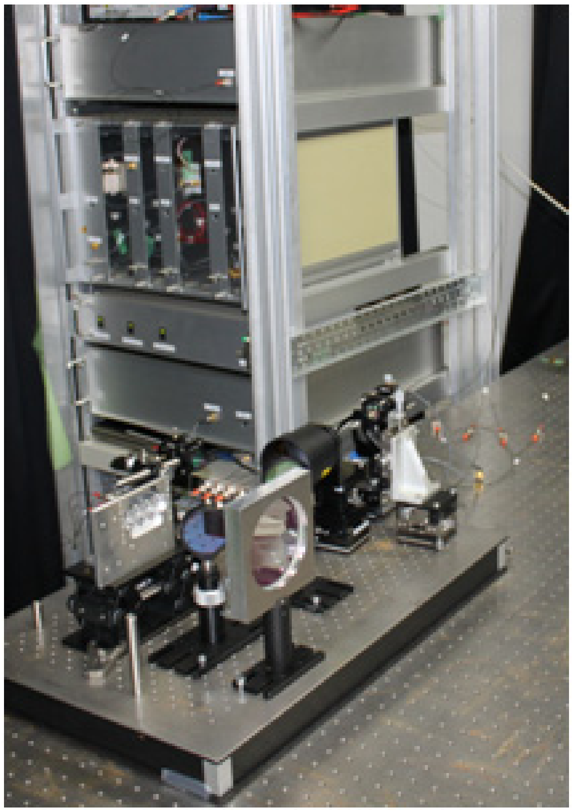

Fig. 2. Snap shot for experimental setup of an optical phase controller

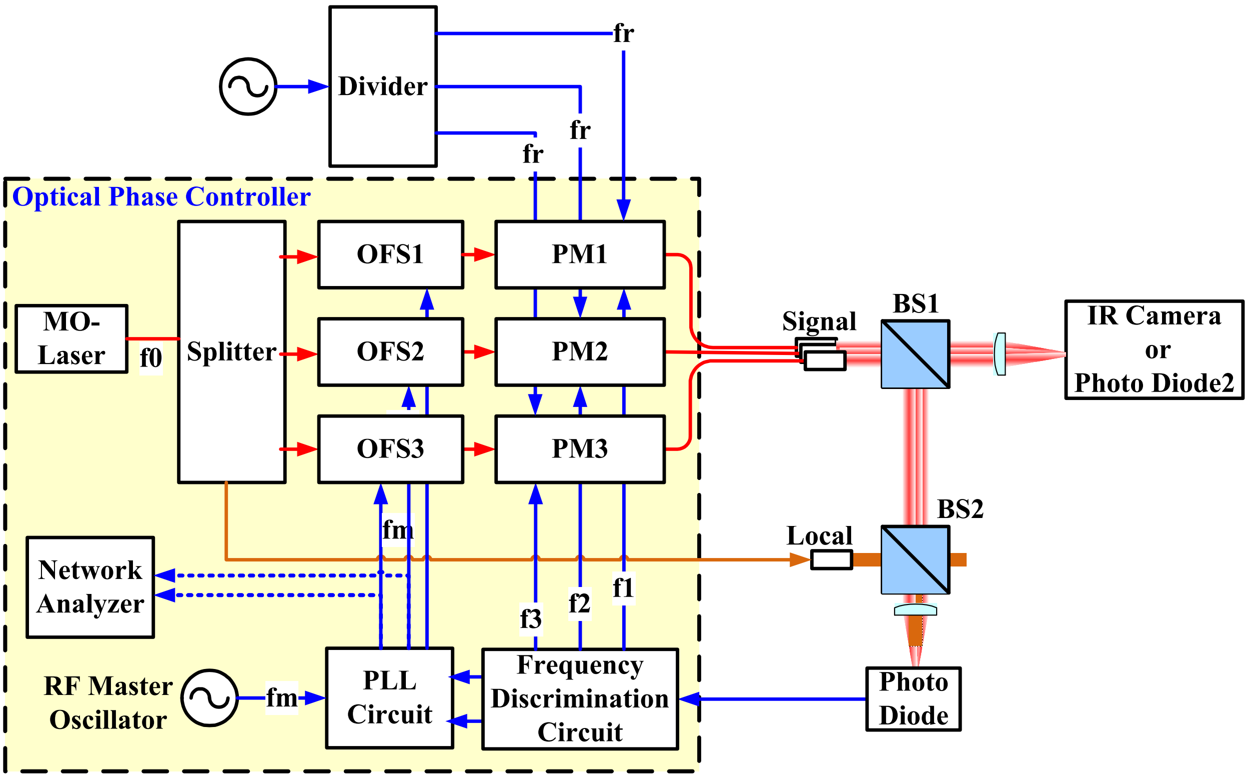

Fig. 1. Block diagram of an experimental setup.

III. Experimental Results

A. Far Field Beam Pattern

At first far field pattern has been measured. The beam combination results are shown in Fig. 3. Fig. 3. shows the FFP of (a) incoherently added 3 beams (PLL OFF) and (b) coherently added 3 beams (PLL ON) and the far field intensity along the x-axis. Comparing the coherently added beam to incoherently added beam, the peak intensity ratio is evaluated is 2.9. This measurement result shows good agreement with a designed peak intensity ratio of 3.

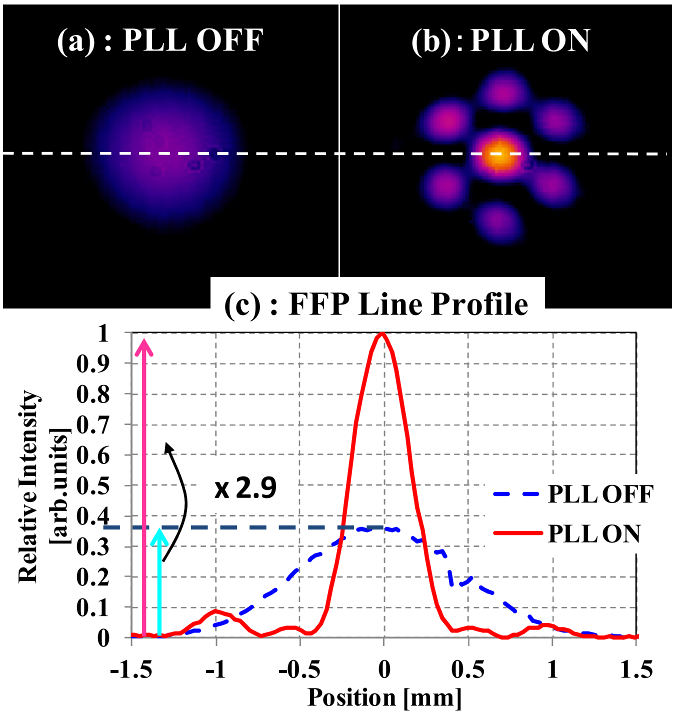

Fig. 3. (a) Far Field Pattern in turning off PLL, (b) Far Fiedl Pattern in turning on PLL and (c) Far field intensity along the x-axsis

B. Optical Phase Locking Performance

Optical phase locking performance has been tested by measuring output signals of PLL circuits. Fig. 4. shows that the measurement result of residual phase error. When the PLL circuits turned on, the residual phase error is decreased less than 0.2 degrees compared to phase error of 70 degrees when the turning PLL OFF. Fig. 5. Shows the phase noise spectrum in the case of turning on and off the PLL circuit. When the PLL circuits are turned on (PLL ON), the phase noise is decreased on frequencies up to 10 kHz.

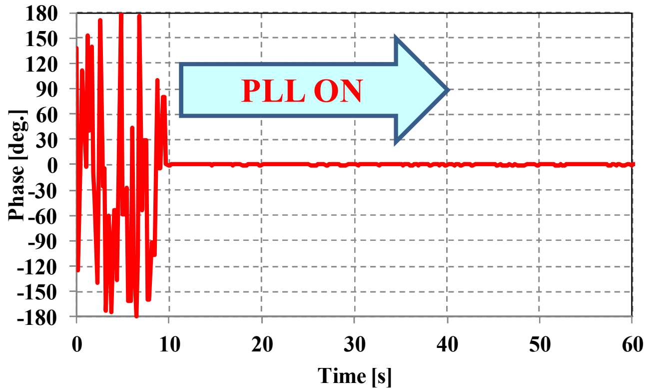

Fig. 4. Measurement result of the phase error between 2 optical signals.

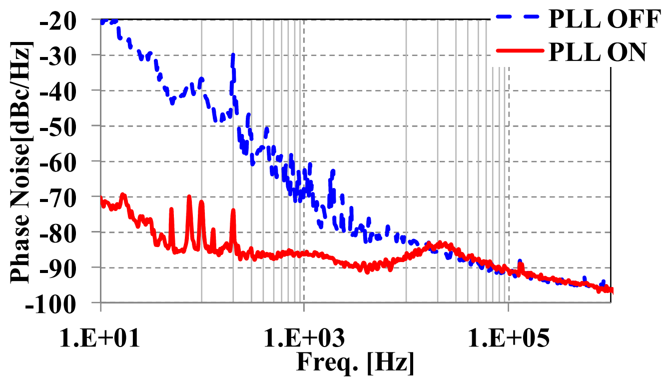

Fig. 5. Measurement result of the phase noise of the PLL circuits output signals. PLL OFF is measured phase noise in PLL circuits turning OFF and PLL ON is measured in PLL circuits turning ON.

Next, we evaluated the RF signal power stability on coherent combined beam. Fig. 6. shows the comparison of RF power fluctuation where PLL is turned on and off. In the free running, RF signal power fluctuated with a range of 43 dB over 30 sec. While the PLL circuits turned on (PLL ON), RF signal power was stabilized with its fluctuations less than 0.05 dB.

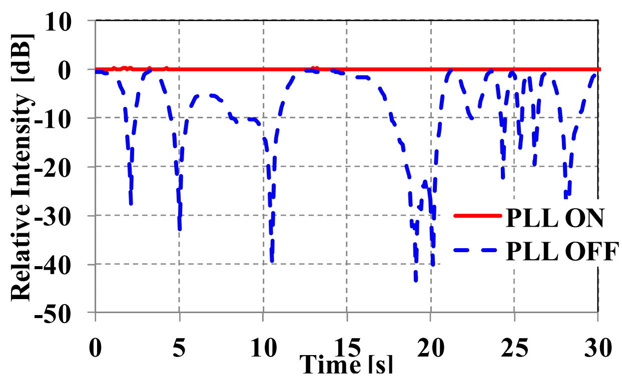

Fig. 6. Measurement result of the RF signal power stabilization at 3 GHz.

IV. Conclusion

We have demonstrated on the optical phase locking of three optical beams to apply optically beam former for receiving phased array antenna. When phase locking was obtained, we ensured phase error between optical signals and transmitted RF signal power fluctuated is 0.2 degrees and 0.03 dB. These results show the feasibility optically controlled beam-shaping, beam-scanning.

References

[1] N. Riza, ED., "Selected papers on photonics control systems for phased array antena", SPIE Milestone Series. Bellingham: SPIE Optical Engineering Press, 1997, vol. MS 136.

[2] A. Kumar, "Antena Design With Fiber Optics". Artech House Publishers, 1996.

[3] H. Zmuda and E. N. Toughlian, "Photonics Aspects of Modern Radar." Artech House, Inc., 1994.

[4] O. Shibata, K. Inagaki, Yu Ji and Y. Karasawa. "A Multibeam Receiving Array Antenna by Means of Spatical Optical Signal Processing", Antennas and Propagation Society International Symposium, 1997. IEEE.

[5] O. Shibata, K. Inagaki, Y. Karasawa and Y. Mizuguchi. "Spatial optical beam-forming network for receiving-mode multibeam array antenna - proposal and experiment." Microwave Theory and Techniques, IEEE Transactions on. vol. 50, Iss. 5, p1425.

[6] E.Haraguchi, T. Ando, J. Suzuki and Y. Hirano, "Coherent beam combination of multiple phase modulated optical signals for a coherent Doppler LIDAR", 17th Coherent Laser Radar Conference, 2013.