Beam-Forming Network Characteristics of Spatial Optical Signal Processing Array Antenna for Multibeam Reception

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ABSTRACT

We have experimentally investigated the basic characteristics of a beam-forming network in a spatial optical signal processing array antenna for multibeam reception. In this experiment, two RF signals, which were simulated multibeam antenna receiving signals from different directions, were separated according to the signal arrival direction in the optical domain. The obtained results generally agreed with calculated values.

INTRODUCTION

A multibeam receiving array antenna requires a beam-forming network (BFN) to separate signals according to the signal arrival direction. Several techniques such as the microwave domain BFN or the digital domain BFN have been proposed to construct the BFN. Spatial optical signal processing is a BFN technique that uses optical spatial Fourier transmission. It has great advantages in terms of the bandwidth, circuit complexity, size, and weight over conventional techniques that use microwave BFN or digital beam-forming antennas.

ATR has proposed a beam shaping, beam scanning, and multibeam transmitting array antenna that uses spatial optical signal processing in its BFN [1],[2]. However, with receiving mode spatial optical signal

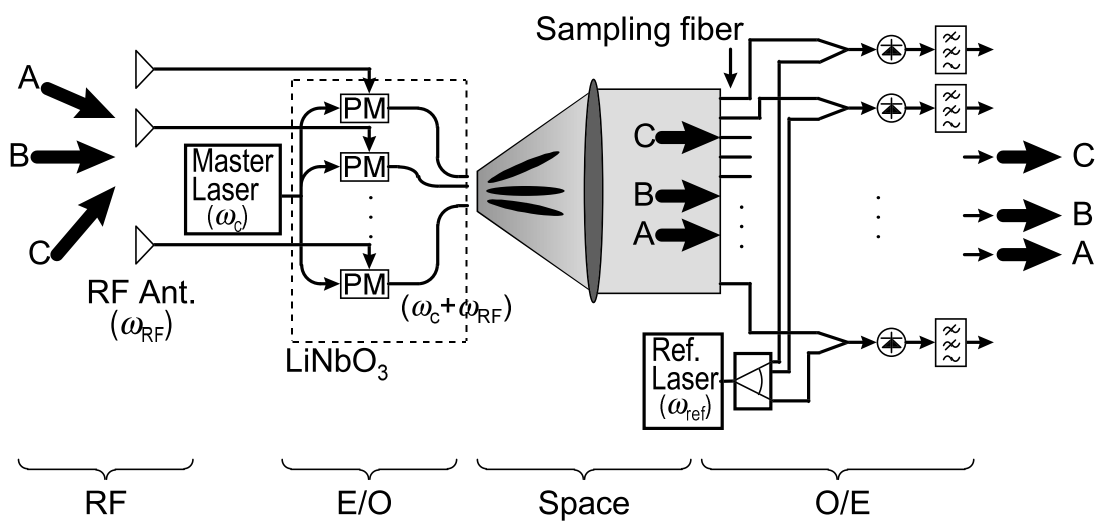

Figure 1. Schematic view of Spatial Optical Signal Processing Array Antenna

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processing, it is quite difficult to achieve optical phase stability i.e. to maintain equal optical path-length conditions. We have proposed a concept for receiving mode spatial optical signal processing array antennas [3],[4]; in order to achieve equal optical path-length conditions, an optical integrated circuit is employed.

In this paper, we present experimental results on the basic characteristics of a spatial optical signal processing BFN for a receiving mode spatial optical signal processing array antenna and verify that the multibeam signals separate in the optical domain.

ANTENNA CONFIGURATION

Figure 1 shows the basic configuration of the proposed spatial optical signal processing array antenna for multibeam reception. This antenna consists of four main parts. The RF part includes RF antenna elements. The electric to optical conversion part (E/O part) includes a laser and an optical PM modulator array. The signal processing part radiates all optical signals into space. The optical to electric conversion part (O/E part) includes photo detectors.

When an RF signal arrives at the RF antenna from a particular direction, there are phase differences between the RF antenna elements. The receiving signal input goes into each PM modulator, and modulates the optical signal from Laser 1. The PM modulator formula is as follow.

$$A_0 \cos\{\omega_c t + m\cos(\omega_{RF} + \phi)\}$$
$$= \sum_{k=-\infty}^{\infty} J_k(m)\cos\{(\omega_c + k\omega_{RF})t + k(\phi + \frac{\pi}{2})\}$$

where ω_c is the frequency of Laser 1, ω_{RF} is the RF frequency, and ϕ is the RF phase. This formula shows that the phase distribution of the first upper side-band component of the modulated signal (k=1) is of the same value as the input RF signal phase distributions. These modulated optical signals are then radiated into space from the edge of the substrate. Note that if we only focus on the first upper side-band component of the modulated optical signal, the radiation direction is dependent on the RF signal arrival direction.

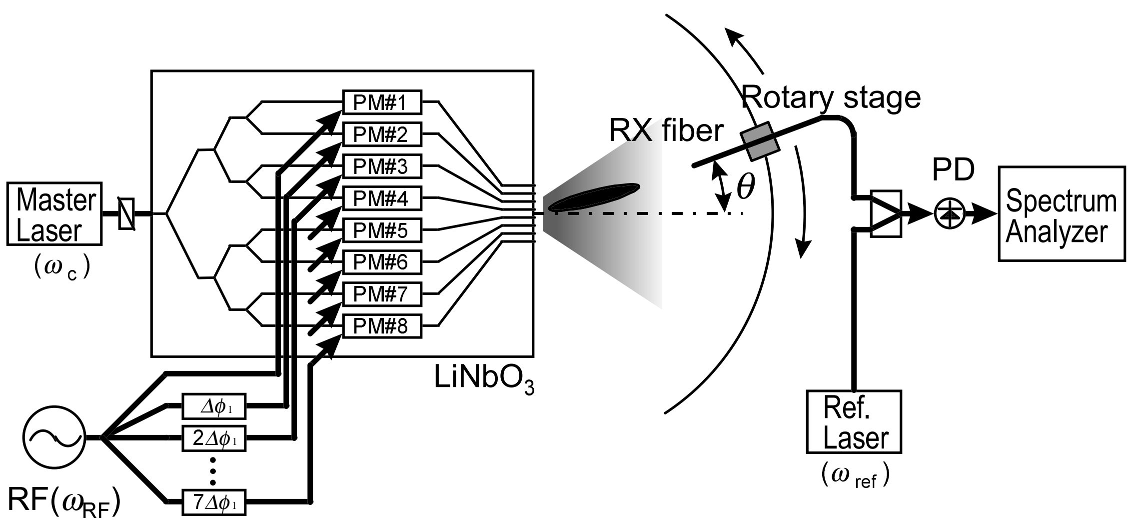

Figure 2. Experimental Setup for a Radiation Pattern of a Spatial Optical Signal Processing Array Antenna

When the multibeam signals arrive at the RF antenna, these signals are separated into the beam arrival directions through the spatial optical signal processing. These signals are then sampled by the sampling fiber and re-converted to RF or IF signals in the O/E part; we can therefore obtain the original signal.

To achieve optical phases stability, we construct the optical phase modulator array in the same substrate using optical integrated circuit technology. Using this configuration, we can construct a BFN using optical signal processing.

EXPERIMENT

We constructed an eight-element optical phase modulator array using optical integrated circuit technology and performed experiments to confirm the optical signal processing behavior.

Figure 2 shows the experimental setup. The input RF signals are simulated actual antenna receiving signals. The input RF signal phase difference between adjacent phase modulators is indicated as $\Delta\phi$, which is determined by the receiving signal direction.

The lasers were phase locked Nd:YAG lasers of the 1.319μm band. The radiated optical signals were sampled by an RX fiber, combined into an optical beam from the reference laser, and detected by a photo-detector (PD). We rotated the RX fiber on the rotary stage and measured the first upper side-band component of the detected signal by a spectrum analyzer to obtain the radiation pattern of the first upper side-band component of the radiated optical signal.

In the first experiment, we measured the radiation pattern when $\Delta\phi$ was changed. In this experiment, the RF signal was a 300MHz continuous wave (CW) and the amplitude at the phase modulator input port was 0dBm. The distance from the substrate to the RX fiber was 22mm.

Figure 3 shows the obtained radiation pattern. The horizontal axis indicates the radiation angle toward the center, and the

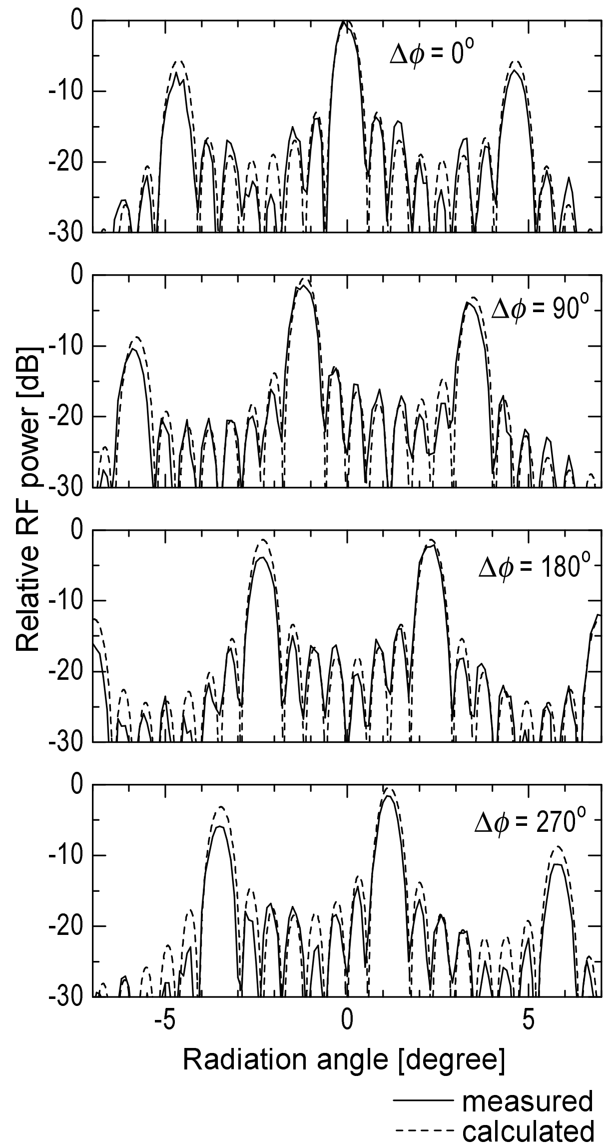

Figure 3. Radiation patterns of the first upper side-band component of a radiated optical beam

vertical axis indicates the amplitude. The obtained radiation pattern is in general agreement with the calculated value; the beam tilted when the RF signal phase distributions were changed. The maximum level of the amplitude is about +60dB higher than the noise level.

In the second experiment, we also measured the optical radiation pattern when the input RF signals were simulated multibeam signals. RF signals having two different phase distributions were combined and input into the optical phase modulator array. The RF phase distributions $\Delta\phi$ were 0 and 45 degrees, that simulated actual antenna receiving signals with arrival directions that were in the center and 15 degrees tilted toward the center when the simulated antenna element spacing was a half-wavelength. The input RF signal frequencies were 300MHz. To distinguish between the two signals, the signals were amplitude modulated at a different frequency and measurements were made on the modulated signal component at the detected frequency.

Figure 4 shows the obtained radiation patterns. The patterns are in general agreement with the calculated values, and these signals are separated into different angles.

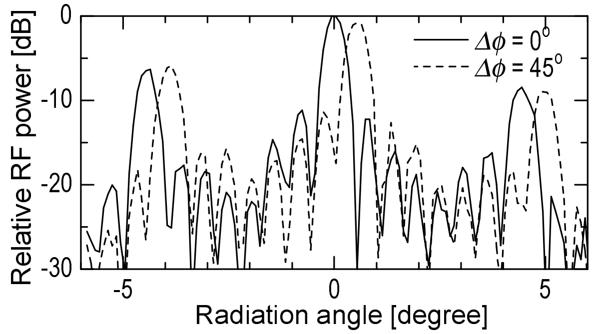

Figure 4. Radiation patterns of the 1st USB of radiated optical beams when multibeam RF signals were input.

CONCLUSION

This paper shows optical radiation pattern characteristics of a beam-forming network in a spatial optical signal processing array antenna for multibeam reception. The obtained results are in general agreement with the calculated values, and the input RF signals, simulated in different directions, are separated according to the beam arrival direction.

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