Proceedings of ISAP'04, Sendai, JAPAN

EXPERIMENTAL RESULTS OF CALIBRATION OF PROTOTYPE DBF ANTENNAS IN KA-BAND FOR HIGH ALTITUDE PLATFORM STATION

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1. Introduction

This paper presents the experimental results of the calibration for reducing amplitude/phase imbalances among the array elements of digital beamforming (DBF) antennas in Ka band. The TX/RX DBF antennas used in the experiments were developed for the proof-of-concept of future communications system using high altitude platform station (HAPS) [1]. Two types of experiments were conducted by using the DBF antennas. One was in unechoic chamber and the other was by using helicopter at an altitude of 3 km. Section 2 describes the specification of the DBF antennas. Section 3 describes the principles of the calibration methods used in the experiments. Sections 4 and 5 present the experimental results in unechoic chamber and by using helicopter, respectively.

2. Specifications of DBF Antennas

Table 1 shows the specifications of the DBF antennas used in the experiment. Figures 1 (a) and (b) show the configuration of the RX and TX DBF antennas, respectively. The antennas are capable of forming 7 fixed beams (as shown in Fig.5 (a)) by the spatial FFT and up to 2 steerable beams toward the users transmitting the signals containing the known reference sequences. The beamforming algorithm is based on the maximal-ratio combining (MRC) assisted by a reference sequence [2].

3. Principles of Calibration for RX and TX Array Antennas

3.1 Calibration for RX Array

(1) Fast Fourier Transform (FFT)-based method (see Fig. 2 (a)): By transmitting non-modulated continuous wave (CW) signal and taking the time-domain FFT of the signal received at each element, the imbalances of the amp./phase among the array elements are obtained.

(2) MRC-based method [3] (see Fig. 2 (b)): Amp./phase of the considered element relative to the reference element (e.g. element #1) are obtained by the complex correlation between the signals of the considered element and the reference element.

3.2 Calibration for TX Array

(1) FFT-based method (see Fig. 3 (a)): By transmitting non-modulated CW signal with regular time offset from each element and taking the time-domain FFT of the signal within the regular time interval, the imbalances of the amp./phase among the array elements are obtained.

(2) Synchronous Orthogonal Codes (SOC)-based method [4] (see Fig. 3(b)): A set of synchronous orthogonal signals $\{s_1, s_2, \ldots, s_m\}$are perturbed by the errors $\{e_1, e_2, \ldots, e_m\}$of amp./phase at each element and transmitted simultaneously from each element. By taking the complex correlations between the signal received at a receiver located in the known direction and each orthogonal signal, the imbalances are obtained. Compared to the FFT-based method in Sec. 3.2 (a) above, this method has the advantages of shorter time for calibration process and availability even in the environment that other signals are being transmitted.

4. Experimental Results in Unechoic Chamber

Figures 4 (a) and (b) show the relative errors of amplitude/phase at each element of the RX antenna obtained by the FFT-based method and the MRC-based method in unechoic chamber. The results by the MRC-based method agree well with the FFT-based methods. Figures 5 (a) and (b) show the measured multibeam patterns (beam #3, #4, #5) of the RX antenna before/after the calibration. Beam

ISBN: 4-88552-206-4 C3055©IEICE

patterns were drastically improved after the calibration. These results verified that both calibration methods worked properly. Figures 4 (c) and (d) show the relative errors of amplitude/phase at each element of the TX antenna obtained by the FFT-based method and the SOC-based method. The results by the two calibration methods also agree well.

5. Experimental Results by Using Helicopter

Prior to a proof-of-concept experiment of communication system using HAPS at an altitude of 20 km, the experiment by using helicopter station-keeping at an altitude of 3 km was conducted. The DBF antennas described in Sec.2 above were mounted in the rear of the helicopter and the calibration tests for RX/TX described in Secs.3.1 (a)/3.2 (b) were conducted under the condition that the ground TX/RX antennas were located at the nadir point of the helicopter as shown in Fig.6. Since real-time processing for the calibration was not available in this experiment, the calibration factors were calculated on an off-line basis and those factors were used in the following flight test. Fig.7 (a) shows the range of power received by each fixed beam (#1 - #7 shown in Fig.5 (a)) formed by the onboard RX DBF antenna before/after the calibration in the case that the signal was transmitted from the ground antenna located at the nadir point of the helicopter. Fig.7 (b) shows the range of power received at the nadir point on the ground in the case that signals were transmitted by 7 fixed beams formed by the onboard TX DBF antenna. In both cases, the power level by each beam was improved after calibration and the level by the center beam (#4) became the largest, as expected. However, the differences between the power levels by the center beam and the other beams were not sufficient even after calibration, since the calibration was not perfect because of the vibration of the helicopter, non-stable attitude of the helicopter, the effect of scattering by the baggage bin etc. Figure 8 shows the patterns of the three beams (#3, #4, #5) of the onboard RX DBF antenna after calibration. These were measured while the helicopter was moving straightforward at an altitude of 3 km over the ground antenna. It is observed that three beams with beamwidth of approx. 13 degrees are formed at an interval of 9 degrees although the peak levels of the three beams are different.

6. Conclusion

Experimental results in unechoic chamber showed that the calibration used in the experiments worked properly. However, accuracy of the calibration was not enough in the experiment by using helicopter.

References

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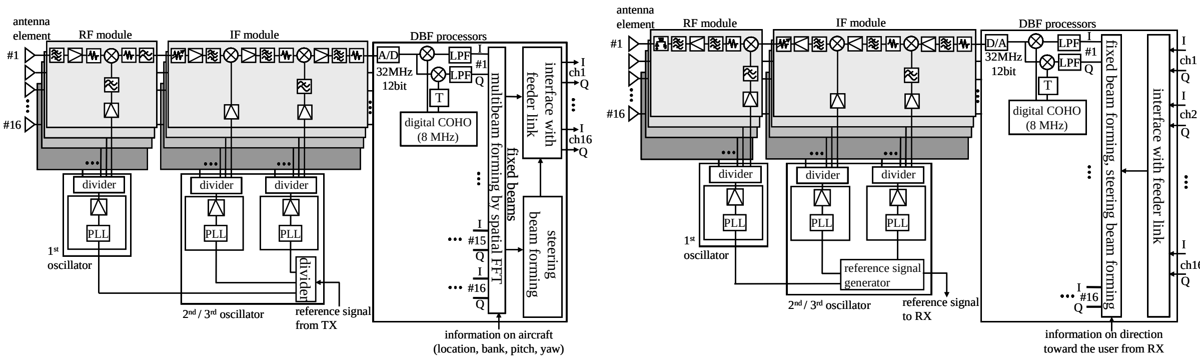
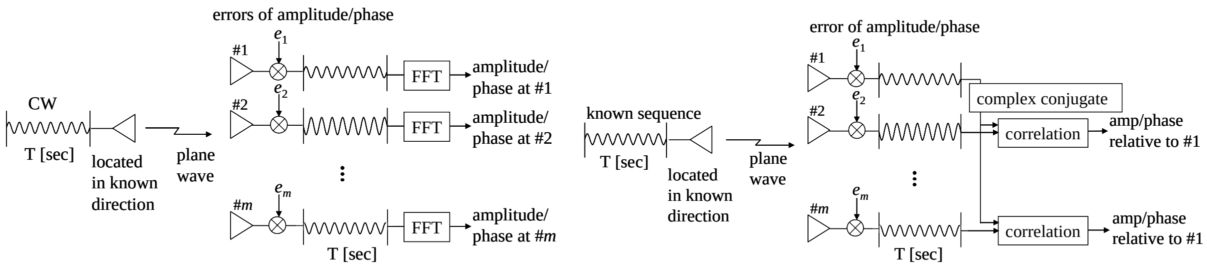
Table 1 Specifications of DBF antennas developed for proof-of-concept of communications system using HAPS

RF	center frequency	experiment in nechoic chamber TX: 30.472 GHz , RX: 20.744 GHz experiment by using helicopter TX: 28.168 GHz , RX: 31.112 GHz
	array structure / radiating element	4 x 4 square array with element spacing of 1.2 λ / patch antenna
	polarization	circular polarization (polarization is converted from linear to circular and vice versa by using meander-line polarizer in front of the antenna plane)
	antenna gain / beamwidth	15.7 dBi (RX/TX) / 13 degrees (RX/TX)
	TX e.i.r.p. / TX power(element) / RX G/T	11 dBW / 16 dBm / -15 dB/K
IF	frequency	8 MHz
digital signal processor	structure	TX: FPGA (100 k gate) x 31, RX: FPGA (100 k gate) x 61
	sampling frequency/resolution /bandwidth	32 MHz / 12 bit/ approximately 4 MHz
	available number of beams	RX:7 (fixed), 2 (steerable, MRC-based algorithm with reference sequence) TX:7 (fixed),2(steerable, based on the data of DoA received from RX system)



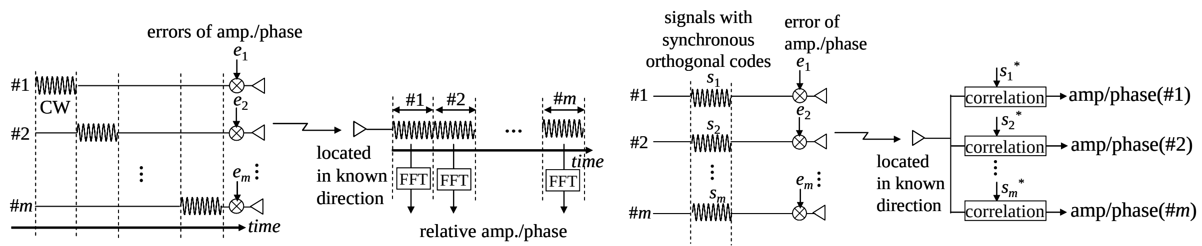
(a)RX antenna system (b) TX antenna system

Fig.1 RX/TX DBF antenna configuration



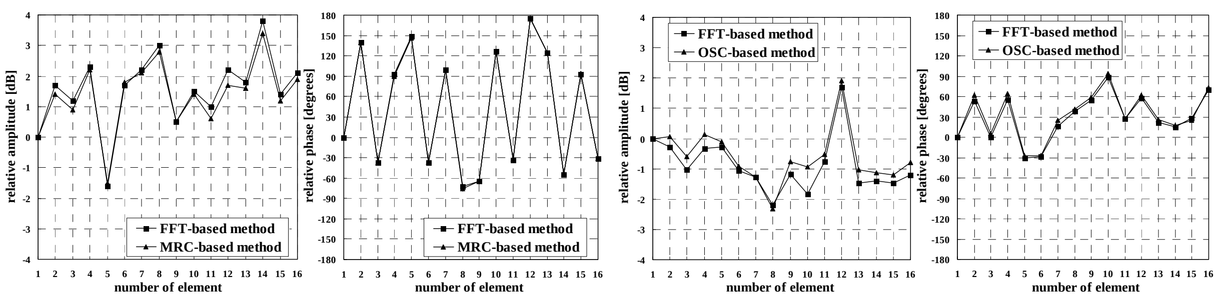
(a)FFT-based method (direct measurement) (b) MRC-based method

Fig.2 Principles of calibration for RX array antenna



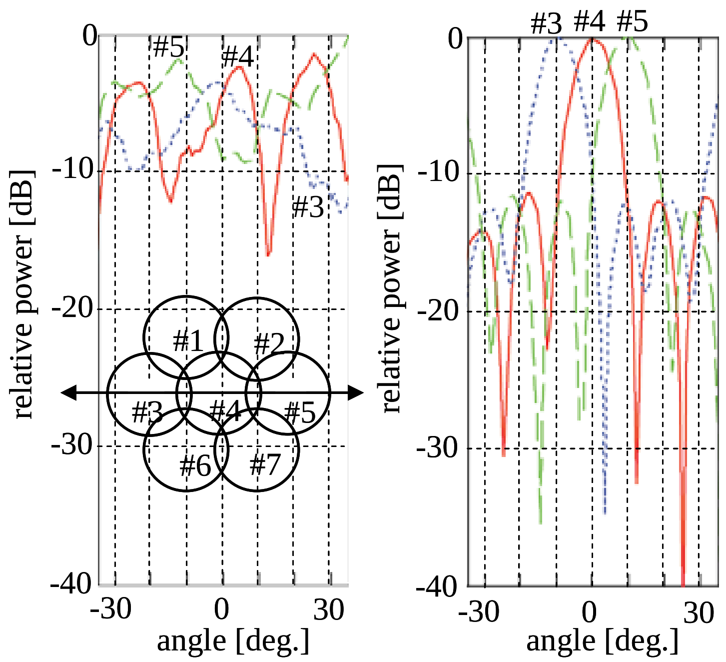
(a)FFT-based method (direct measurement) (b) SOC-based method

Fig.3 Principles of calibration for TX array antenna



(a) amplitude in RX (b) phase in RX (c) amplitude in TX (d) phase in TX

Fig.4 Relative errors of amplitude and phase



(a) before calibration (b) after calibration

Fig.5 Multibeam patterns measured in unechoic chamber

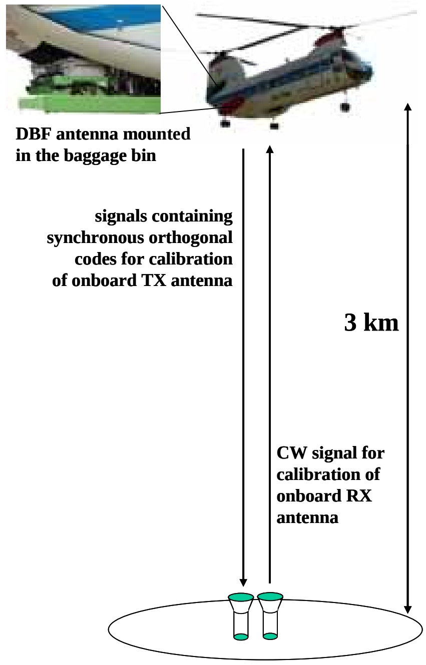
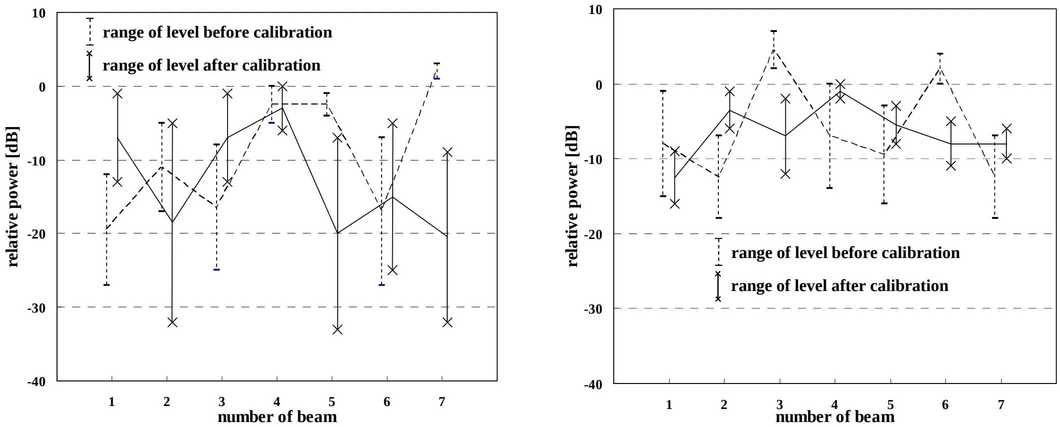


Fig.6 Experimental system using helicopter



(a) relative received power by each beam of RX (b) relative transmitting power by each beam of TX

Fig.7 Receiving/transmitting power by each beam before/after calibration

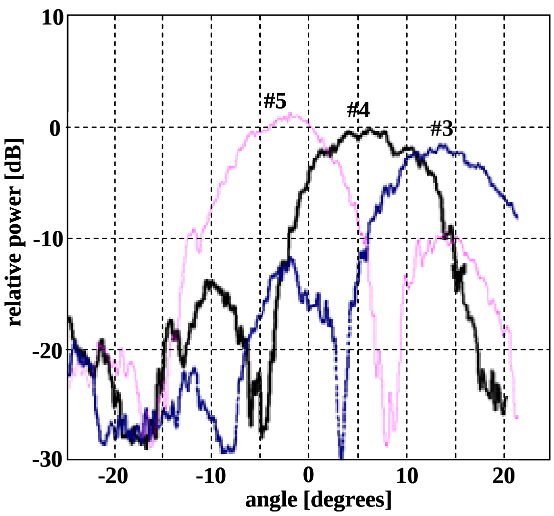


Fig.8 Multibeam patterns of RX DBF antenna measured by a straight flight