Feasibility Study on Delay Difference Estimation through Space for Phased Array Antennas

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***Abstract* - We address delay calibration of phased array antennas with true time delay. We propose a delay difference estimation method between two elements through space. It is applicable to systems for which wired measurements are impossible. Additionally, phase measurement is not required. In this paper, we demonstrate feasibility of the proposed method in an actual array case and a limited measurement environment. The delay difference was estimated with small error which was sufficiently smaller than 1λ. Additionally, it worked well when the propagation distance was only 2.6 times compared with the aperture size.**

***Index Terms* —True Time Delay, Phased Array Antenna, Delay Calibration.**

1. Introduction

Phased array antennas (PAAs) have been widely used because of the advantage of electrical beam scanning. In order to control the exciting phase of antenna elements, phase shifters are generally used. When large aperture and wide frequency band are needed, in order to avoid the squint, transmission timing of each element is controlled by the true time delay (TTD) [1].

In most of PAAs, amplitudes and phases of elements are not uniform in initial state due to cable length or transmission characteristics error of RF devices. The calibration method has been proposed [2]. For TTD systems, in addition to the phase calibration, delay calibration is required. We have proposed a method of estimating the delay difference between two antenna elements [3]. Because the method needs only received level measurement with frequency sweep, phase measurements using a vector network analyzer are not required. Additionally our method suits systems for which wired measurement is difficult because of measurement through space. We demonstrated that delay difference could be estimated with small error by small experiment using stand-alone two antenna elements. However the feasibility in actual array case was not confirmed. In this paper, we demonstrate the delay estimation by using the actual 16-element array.

2. System Configuration and Delay Estimation

The system configuration is shown in Fig. 1. Though one TTD may be connected to multiple phase shifters/elements in practical PAAs [1], one TTD is connected to one element for simplicity in this paper. We define delay difference between pass (A)-(B)-(D) and pass (A)-(C)-(D), due to TTD as t_{TTD}, due to propagation as t_r, due to wired pass like cable length or individual differences in the analogue circuits as t_{system}, and total pass difference as T. We assume that t_{TTD} is variable and ideal because digital synthesizer recently can be used as TTD. Our goal is to estimate the delay, especially t_{system} between two passes.

The estimation method [3] is briefly introduced here. Two elements within all elements are driven and an already-known delay difference is set for t_{TTD}. When the frequency is swept, a cosine-shaped electric field E is received as

$$|E| \propto \left|1 + e^{-j2\pi f T}\right|, \qquad (1)$$

where f is frequency, T is a summation of delay differences,

$$T = t_{TTD} + t_{system} + t_r. \qquad (2)$$

An example of the received signal is shown in Fig. 2. T is estimated from the cycle F of the received signal as $T=\pm 1/F$. This method utilizes actively high value as t_{TTD} which controls the value F to observe one or more cycles within available frequency bandwidth. t_r can be calculated from the path length or by direct measurement in case of short distance. Therefore t_{system} can be estimated from (2).

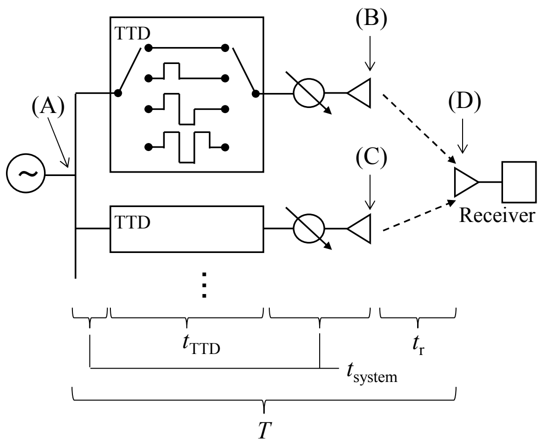

Fig. 1. PAA system with TTD.

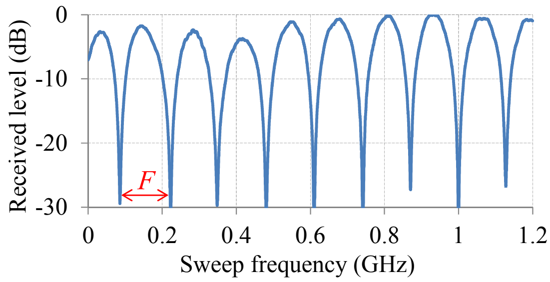

Fig. 2. An example of received electric field.

3. Experiment Using 16-Element Array

The experiment system is shown in Fig. 3. Unfortunately we could not use actual TTD device, the equivalent system was built by using analogue RF components. The known delay difference t_{TTD} is given by difference of cable length. One signal path with long cable is always connected to element No. 9 as reference. Other signal path with a trombone phase shifter is connected to each element. In this experiment, t_{TTD} was 7.91ns by wired measurement when the phase shifter value was 0ps. The trombone phase shifter which changes the cable length simulates t_{system}. We used 16-element array using cavity antenna fed by L-shaped elements [4] in Fig. 4.

An example of received signal is shown in Fig. 2. In the calculation process of cycle F, observed multiple cycles were averaged to reduce the antennas' frequency characteristics. The estimated total delay difference is shown in Fig. 5. It may seem weird because neighboring antennas (No. 8-9) has large difference. Because long cable is connected to No. 9 as per Fig. 3, long propagation path like No. 1 reduces the delay difference between No. 1 and 9. We measured the propagation distance t_r using a laser measure. From (2) and Fig. 5, t_{system} is calculated as per Fig. 6. True plot is abscissa values with opposite sign. The estimation error did not exceed 28ps which was extremely small compared with wavelength. Fig. 7 shows t_{system} of each element when the phase shifter is 0ps. The result shows low dependency of the antenna position even if the actual array with a mutual coupling is used and the propagation distance is only 2.6 times compared with the PAA aperture size.

4. Conclusion

We demonstrated the feasibility of the proposed delay estimation method. The proposed method was able to estimate delay difference between two elements even if an actual array antenna with mutual coupling and short propagation distance were applied.

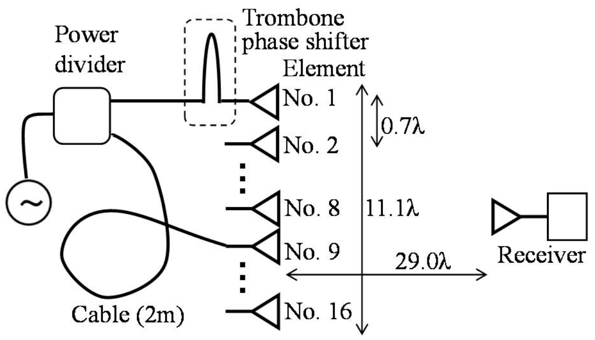

Fig. 3. Experiment system.

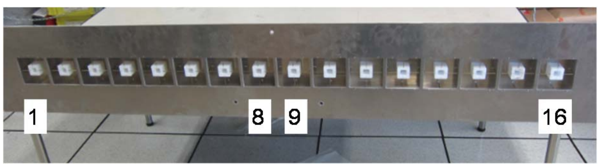

Fig. 4. 16-element array using cavity antenna. (Numbers in the picture indicate element No.)

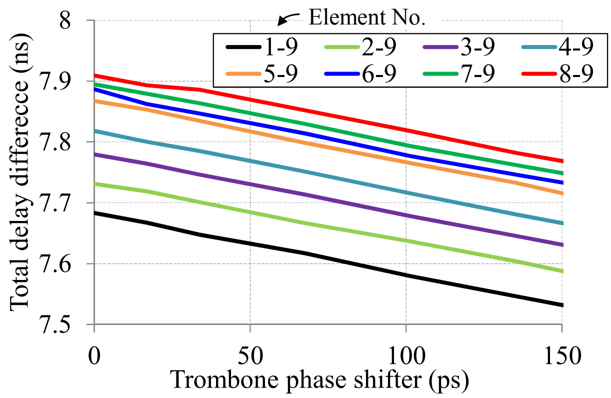

Fig. 5. Total delay difference.

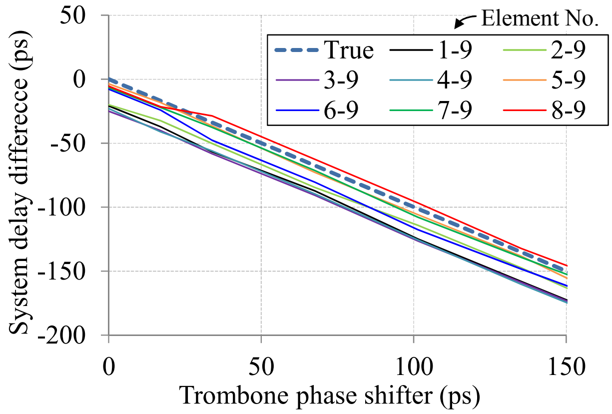

Fig. 6. System delay difference.

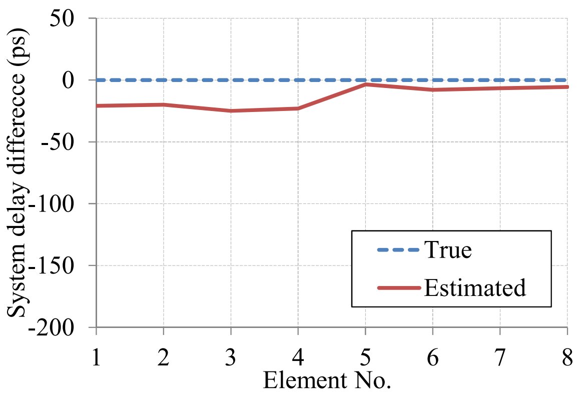

Fig. 7. Element position dependency (at 0 ps).

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