# Study on Multistatic Primary Surveillance Radar using DTTB Signal Delays

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***Abstract*—This paper presents a new concept of a multistatic primary surveillance radar (MSPSR) that uses digital terrestrial television broadcast (DTTB). We proposed a passive bistatic radar using DTTB signal delay in a previous work. During further study, we found that the system could detect signal delays from moving aircraft. The coverage area of the proposed system was also confirmed by comparing with ADS-B. Thereafter, we expanded the bistatic radar system to a multiple-receiver system, in order to realize MSPSR configuration. In this paper, a surveillance system using two receivers is introduced. First, the basic principle of the MSPSR system using DTTB signal delays is reviewed. Then, a preliminary experiment performed in the Tokyo bay area is presented. Results show that the delayed signals caused by moving aircraft can be detected at the two receivers at the same time. Finally the positional estimation using two receivers is discussed.**

## I. Introduction

Airport surveillance radars typically include a primary surveillance radar (PSR) [1] and a secondary surveillance radar (SSR) [2]. As the SSR uses the reply signals from an aircraft and provides various information such as the aircraft's position, identity and altitude, it has become the main surveillance system in air traffic management. On the other hand, the PSR also plays an important role as a backup and improves the security of operations, because it uses the waves scattered by aircraft and is a type of independent noncooperative surveillance system. However, the update and detection rates of PSRs are lower than those of SSR technologies. Consequently, PSR application technologies are required to be developed to improve the operational security.

Recently, multistatic primary surveillance radar (MSPSR) [3], [4] has attracted the attention of researchers. MSPSR can cover the shadow areas of the conventional PSR and can be used as a PSR alternative. In addition, it may be useful for improving the safety of transponder operations. As the MSPSR is classified into passive bistatic radar, it can select illuminators of opportunity , e.g., present radar signals (e.g. PSR and SSR), digital terrestrial television broadcasts (DTTB), mobile communications (e.g. 3G and LTE), global navigation satellite system, and so on [5]. The radar specification depends on the signal type that is employed. An ultimate MSPSR system is a combination of several passive radars using different sources. Among them, the DTTB is considered the most promising radio wave to cover a larger area because its transmitted signals are always present and its transmitted powers are relatively larger than other illuminators.

We proposed a radar concept using the DTTB signal delays, which are easily detected as an original characteristic of DTTB [6]. In the field tests, we confirmed that the proposed system could detect the scattered waves from a moving aircraft. The bistatic ranging was estimated based on the delay profiles. According to our system concept, the update rate was achieved within a second. However, the basic concept relied on a directional antenna. Therefore, only the approximate aircraft positions could be determined by using the intersection of the antenna direction and ellipsoidal curves obtained from the time-difference of the arrivals of the scattered waves. The use of multiple receiver configurations can determine more accurate positions for moving objects and help realize MSPSR.

In this paper, we propose the concept of MSPSR using DTTB signal delays, which is extended from the basic bistatic radar system. The proposed system uses two receivers that are located separately. First, the basic concept using DTTB signal delays is reviewed, and then, the extended system is introduced. As the proposed system is the first approach to achieving an MSPSR system, the two receivers are not synchronized precisely. However, we confirmed that the system could estimate the moving object position from the intersections of bistatic ellipsoidal curves. The preliminary experimental results are shown in this paper. Finally, we discuss the possibilities of the proposed system.

## II. Principle of DTTB Surveillance System

### A. ISDB-T

Our proposed system is based on the passive bistatic radar and the use of DTTB signal delays. The Japanese DTTB adopted the integrated services digital broadcasting - terrestrial (ISDB-T) standard [7], which was one of the DTTB standards. The ISDB-T provides reliable high quality video, sound, and data broadcasting. The system is rugged and reliable because it employs OFDM modulation, two dimensional interleaving, and concatenated error correcting code [8]. Its modulation scheme is called band segmented transmission - OFDM (BST-OFDM), and accordingly, it has better multipath immunity than other methods.

The Japanese DTTB is assigned to the UHF band from 470 to 770 MHz. Each bandwidth is 5.572 MHz, and is divided into 13 OFDM segments that have different carrier modulations and encoding rates of error correction. Therefore, ISDB-T can simultaneously provide some services. One of the significant properties of ISDB-T is the guard interval (GI), as shown in

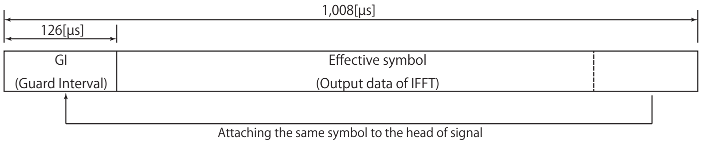



Fig. 1: Guard interval with 1/8 of effective symbol length.

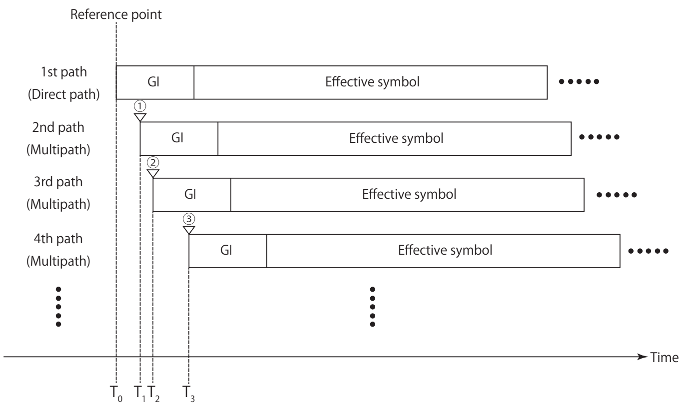



Fig. 2: Detection of starting time of GI. $T_n$ corresponds to the arrival time from each target.

Fig.1. The aim of the GI is to absorb interferences of delayed signals caused by multipath. The GI is generated by attaching a portion of the latter effective symbol to the signal heading. In the mode 3 system, the length of GI is 1/8 of effective symbol length. Therefore, each signal length is 1008 $\mu s$ with a GI of 126 $\mu s$.

### B. Detection of Signal Delay and Bistatic Ranging

In real situations, many multipath signals are observed as shown in Fig.2. Multipath is generally unnecessary signals in the broadcast system. They are, however, important for finding moving objects. The procedure of multipath detection is described here.

The detection of the signal delays starts from searching the signal heading. First, the starting position of each signal is determined by autocorrelation or by finding the pilot carriers, which are defined by the ISDB-T regulation. Next, minimal FFT windows are applied in order to include as many signal delays as possible. Finally, the signal peaks are searched.

Multipath caused by statistic and dynamic objects are expressed as signal delays, by the time-difference of arrival for the direct wave. Once the signal delays are determined, ellipsoidal curves corresponding to the passive bistatic ranging can be drawn when the source and receiver positions are known. Fig. 3 illustrates the conceptual bistatic ellipsoidal curve. These positional relations are given by

$$c\tau = L_1 + L_2 - L_0 \quad [m] \tag{1}$$

where $L_0$ is the direct distance from the source to the receiver, $L_1 + L_2$ is the total propagation distance from the source to the receiver via a target, and $c$ is the light velocity. In the experiment, the source and receiver positions are known

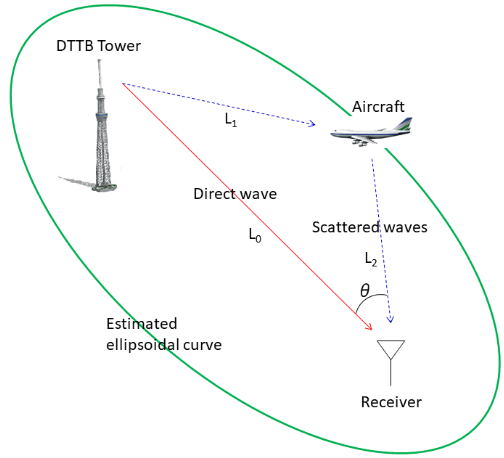



Fig. 3: Bistatic ellipsoidal curve.

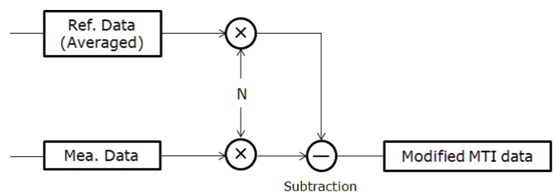



Fig. 4: Modified MTI procedure.

parameters and the delay $\tau$ is estimated using the concept described above.

### C. Suppression of Static Obstacles

Scattered fields from moving aircraft are much smaller than direct waves and scattered waves from static obstacles. It is difficult to pick up only the desired signals from among all the unnecessary signals. Therefore, we employed a modified method of moving target indication (MTI). Signal delays from moving targets are generally dynamic factors and change depending on the aircraft characteristics such as aircraft size and attitude. However, signal delays from fixed structures are almost static and do not change. However, the received signals in the real environments fluctuate in the time dependence. Therefore, when using the averaged signal power obtained in an arbitrary time span, only dynamic scattered waves are prominent. The average relative received power is given by

$$\boldsymbol{P_i^d} = (P_i^1, P_i^2, P_i^3, \ldots, P_i^M)^{\mathrm{T}} \qquad (i = 1, 2, 3, \ldots, N) \tag{2}$$

$$\boldsymbol{P_{ave}} = \frac{1}{N}\sum_{i=1}^{N} \boldsymbol{P_i^d} \tag{3}$$

where $\boldsymbol{P_i^d}$ is estimated relative received power and superscript $M$ is the number of delayed signals. Fig. 4 shows the modified MTI concept. The modified MTI subtracts the estimated relative received powers of the signal delays from the averaged ones.

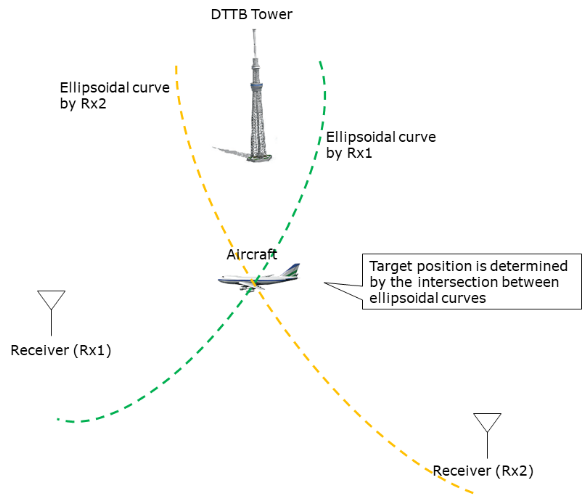



Fig. 5: Two-dimensional target position computed by two ellipsoidal curves.

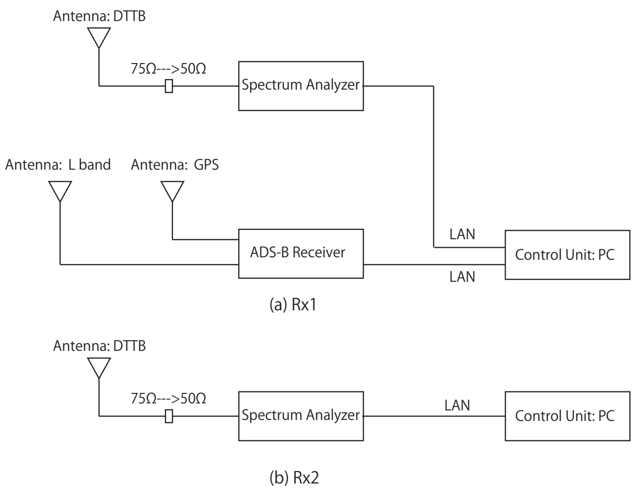



Fig. 6: A concept of MSPSR using DTTB signal delays.

## D. Concept of Multistatic Radar

An expanded system based on the basic radar concept using DTTB signal delays is introduced in this subsection. The expanded system consists of two receivers. If the two receivers are located separately, they draw different ellipsoidal curves. Intersections between the two curves indicate the two-dimensional position of the moving object, as shown in Fig. 5.

Next, a structure of the proposed system is presented. As shown in Fig. 6, two receivers and an ADS-B receiver unit are used in the proposed system. The first receiver unit (Rx1) has a main function and consists of a receiver for DTTB and an ADS-B receiver. ADS-B is used for the radar reference. The second receiver unit (Rx2) is a subsystem and consists of only a receiver unit of DTTB. Rx2 is the basic structure of the proposed surveillance system [6]. In this paper, we used a spectrum analyzer with the DTTB software to simplify

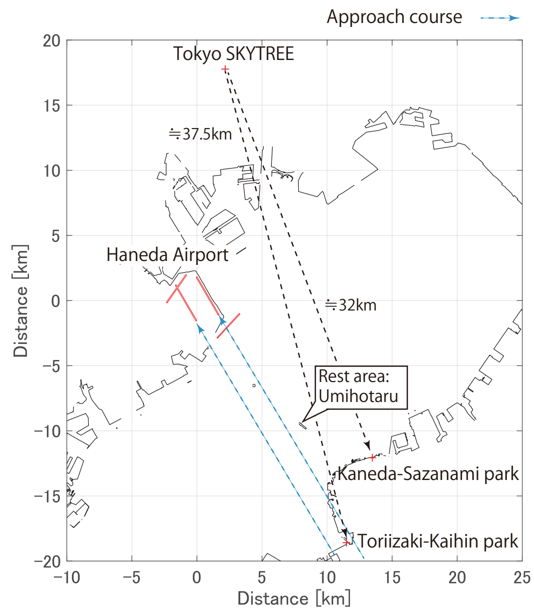


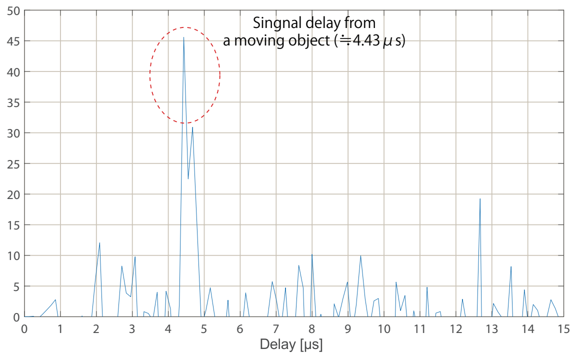

Fig. 7: Experimental environment.

the systems. The external signal processing units operate the spectrum analyzers and record the signal delays. The recorded signals are processed off-line. It should be noted that the two receivers are located far from each other, otherwise it would not be possible to obtain a moving object's position because the ellipsoidal curves have almost the same shapes. Time synchronization between receivers is extremely important, but in this paper, we employed the internal PC time from a preliminary experiment. The internal PC time was corrected in advance by using a time server.

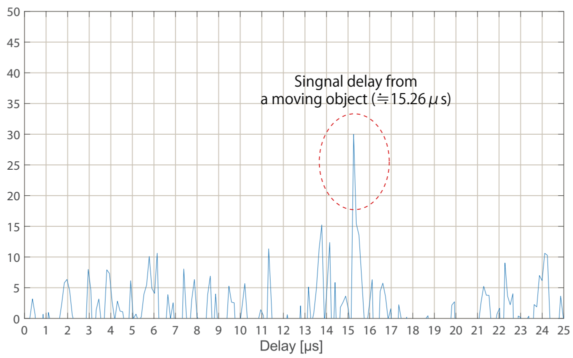
## III. Experimental Result

An experiment was performed at two locations in the Chiba Prefecture, Japan, with the locations facing Tokyo bay. Fig. 7 shows a positional relations and experimental environment. A main receiver (Rx1) is located at Toriizaki-Kaihin park, which is indicated at the lower-center side of the figure, and a sub-receiver (Rx2) is located at Kaneda-Sazanami park, which is indicated slightly above Rx1. The distance from the transmitter to the two receiver positions are approximately 37.5 km and 32 km, respectively. Two antennas corresponding to Yagi antennas with 14 and 20 elements are selected as receiving antennas, and their directions are set toward the rest area called Umi-Hotaru.

Fig. 8 shows the experimental results of the delay profiles, which were processed by the modified MTI. Two data were picked up at the same time. The doted circles indicate signals from the moving object detected by each receiver. A signal delay from the moving object of Rx1 appears at approximately 4.43$\mu s$, and that of Rx2 appears at approximately 15.26$\mu s$. From these delays, the target position is determined. Fig. 9 shows computed ellipsoidal curves. Using two curves, two intersections are obtained. A lower point is close to Rx2, and its points are different from the direction of the directional




(a) Delay profile of Rx1




(b) Delay profile of Rx2

Fig. 8: Delay profiles at same record time.

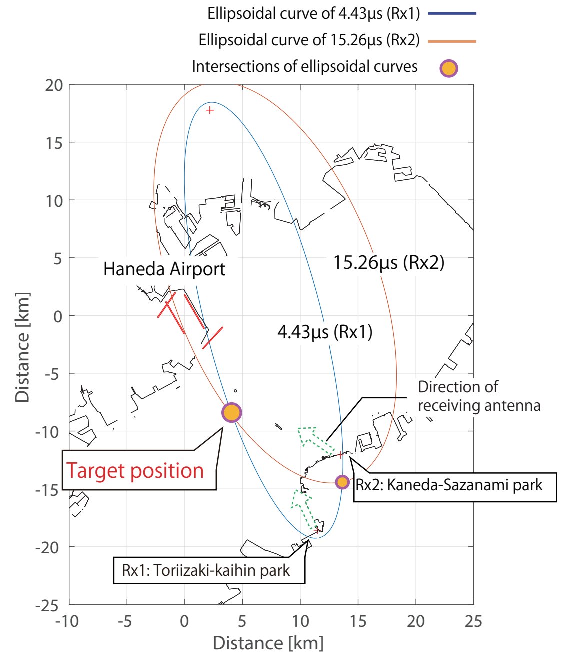



Fig. 9: Ellipsoidal curves drawn by two delays.

antenna. Therefore, we conclude that the center position is the moving target position. This is almost indicated on the approach course shown in Fig.7.

In this paper, we have estimated the target position by using two receivers, which enables us to compute the two-dimensional position. We assume that the target position is determined by selecting an intersection point from two estimated points, but actually a more precise solution is required. To overcome this problem, three or more receivers are needed. However, in this preliminary experiment, we have found that the multiple receiver configuration could estimate the moving target position.

## IV. Conclusion

MSPSR using DTTB signal delays was proposed in this paper. First, the basic principle of the system was presented, and the configuration employing multiple receivers was subsequently introduced. In order to confirm the proposed system functioning, preliminary experiments were performed. The experimental results showed that two receivers detected the signal delays from the moving object at the same time. Based on the signal delays, ellipsoidal curves were computed. Finally, the target position was estimated by using the intersection of the ellipsoidal curves.

In this paper, we used only two receivers. In order to obtain more accurate positions, three or more receivers are required. In addition to that, time synchronization should be considered. They deserves as future works.

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