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DEVELOPMENT OF PASSIVE SURVEILLANCE RADAR

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Abstract

Electronic Navigation Research Institute (ENRI) and IRT Corp. have been developing of a Passive Primary/Secondary Surveillance Radar System (PPSR/PSSR) in collaboration since 2008. In 2009, we developed a PSSR whose size is smaller than size of A4, and in 2011 we also developed a PPSR by using the conventional SSR (Secondary Surveillance Radar) as the master radar station. The first PPSR handles the reflection of 1,030MHz SSR interrogation signals. In 2012, we developed a PPSR that could process the reflection of scanned probe radio waves of 2.8GHz from the conventional PSR (Primary Surveillance Radar). The latest PPSR can provide not only the target aircraft, but also the state of the cumulonimbus.

1 Introduction

The passive surveillance radar referred to in this paper is equipment or a system for the purpose of monitoring positions of aircraft cruising in air space and taxing on the surface of an airport. The passive radar has a function of detecting the position of target objects, such as aircraft, having a reflective cross-sectional area above a certain level without any radio wave transmissions.

Today, many airlines' aircraft have a capability called ADS-B (Automatic Dependent Surveillance - Broadcast), and they are able to determine their position by using GPS, and transmit their position information in a broadcast. The ADS-B receiver that is used in combination with a computer generally has a function of receiving ADS-B information, and it displays the positions of the aircraft on the map like a radar display image. However, if you look at the sequence of aircraft entering at regular intervals in major airports, you can sometimes see a free space that is of twice the distance. It is not uncommon for aircraft without ADS-B capability to be in the free space. The passive radar has a function of detecting and positioning a target object by itself, and the passive radar is a system completely different from the ADS-B system in this sense.

There are many kinds of passive radar systems. One is the PSSR (Passive Secondary Surveillance Radar) corresponding to SSR (Secondary Surveillance Radar) which can handle the radio waves of 1,090 MHz reply signals transmitted from aircraft after receiving 1,030 MHz interrogation signals from SSR. Another is the PPSR (Passive Primary Surveillance Radar) which handles the reflection of the scanning signal of about 2.8GHz transmitted by the PSR (Primary Surveillance Radar) as a component of ASR (Airport Surveillance Radar) from target objects, such as aircraft, cumulonimbus, tornados and so on. And furthermore, we can consider and try to develop a special passive surveillance system that handles the reflection and scattering of radio waves of terrestrial digital broadcasting and FM broadcasts, and so on. Though there are many kinds of passive radar systems, their surveillance function is not limited by the equipment on the aircraft side with the exception of an aircraft having a special function such as a stealth plane.

For example, since all aircraft have to be installed Mode-A/C transponder as an obligation, the PSSR corresponding to the SSR of ASR can monitor all aircraft entering the airport, there is no such situation as some aircraft not being able to be observed in ADS-B monitoring. By the way, implementation percentage of ADS-B capability of aircraft is about 80% even in the aircraft taking off from and landing at Japanese major airports, such as Haneda and Narita Tokyo International Airport. Since the average percentage is a much lower value in the case of regional airports in Japan, it is not possible to conduct sufficient air space monitoring by only using ADS-B.

The passive radar system consists of small antennas and receivers, and it provides almost the same aircraft / target surveillance information provided by the master radar system. Furthermore the passive radar is a system that can be integrally operated with the master radar, and performs the performance features that cannot be conducted with only conventional radar.

2 Passive Secondary Surveillance Radar

There are several types of passive surveillance radar systems, as mentioned above. Since the PSSR handles a relatively strong signal as a reply signal from aircraft, it was thought that the PSSR could be easily developed in the 1980s. Since the PSSR that corresponds to the conventional SSR Mode-A/C could also provide the target aircraft's identification information and its flight altitude, the development of the PSSR was expected from the airlines and small airports that were not provided with SSR information. The PSSR was believed to correspond to the needs of potential users. Therefore, the development of the PSSR prototype was carried out at the Electronic Navigation Research Institute (ENRI) that belongs to the Japanese Ministry of Transport, at the end of the 1980s.

In the IRT Corporation, the development of the passive radar system began as the development of the PSSR to observe the surrounding airspace of Airport in 2006 after almost two decades of trials in the ENRI.

Since the Internet was already widespread in 2006, it was possible to deliver the air traffic information to the destination in real time, if the air traffic service authority, Japan Civil Aviation Bureau, decided to. In addition, in 2006, ADS-B receivers that could be used to connect to a computer were also commonly sold at a very low price, and the development of WWW content on a global scale, with networking the ADS-B information, also progressed.

However, in Japan, no air traffic information was provided for the purpose of noise measurement in the airport installation environment, even though the noise measurement was requested by the JCAB. The PSSR was considered necessary in order to efficiently perform operations that were requested by the JCAB. The PSSR, as the first product of IRT Corp., was delivered as information equipment to support the measurement of noise around airport.

2.1 #PRIRT1-PF-001A PSSR

In the latest models in 2014, the PSSR provided by the IRT Corp., has adopted a system configuration that uses a USB connection between the signal processing unit and the host PC.

Fig. 1 PSSR Receiver / Processor

Fig. 2 Antennae of PSSR

After connecting antennae (shown in Fig. 2) to the PSSR Receiver & Processor (shown in Fig. 1), it is possible to obtain airspace monitoring information such as that shown in Figure 3 and Figure 4. The PSSR (#PRIRT1-PF-001A PSSR) is smaller than A4 size, at a 250mm width, 170mm depth, and 65mm thickness, and a power consumption of 3W or less.

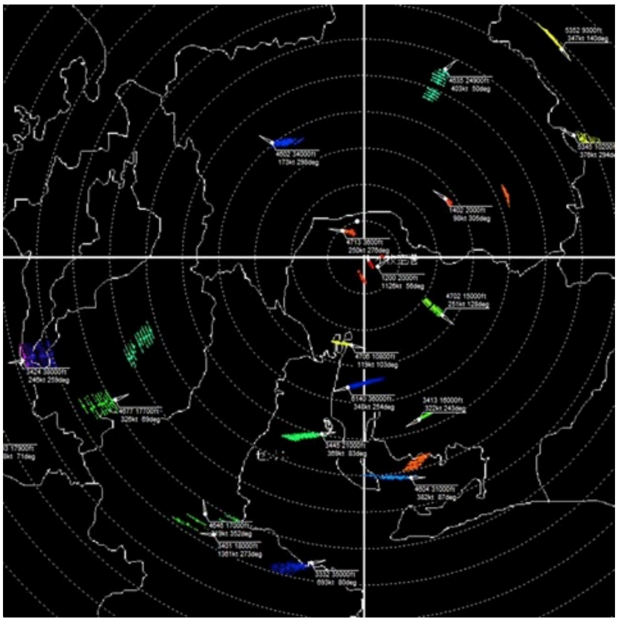

Fig. 3 Airspace Surveillance Information

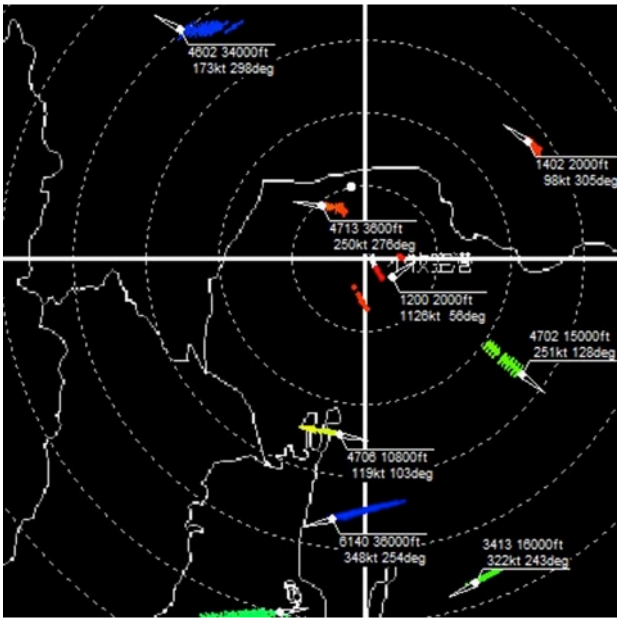

Fig. 4 Close-up of Surveillance Information

The PSSR provides the flight position of each aircraft with its decoded Mode-A identification, Mode-C flight (air pressure) altitude, and calculated heading direction and ground speed. Since the terminal airspace surveillance SSR whose scanning interval is about 4 seconds was set as the master SSR of the PSSR, the trajectories were obtained in about 40 seconds, and are shown in Figures 3 and 4. Each aircraft transmits reply signals approximately 20 times in the every scanning of the master SSR, since the scanning interrogation beam width is about 3 degrees. And aircraft position calculated from every reply signal acquires elliptical arcs corresponding to the interrogation beam width. The elliptical arcs, as the measured positions of aircraft, are displayed in different colors corresponding to pressure altitude (low altitude is a warm color, and high altitude is a cold color).

Airspace monitoring coverage of the PSSR is about more than 200km, and the PSSR can be operated with any conventional SSR Mode-A/C as the master SSR, including the SSR which is installed temporarily for some kinds of operations, such as disaster drills, by Self-Defense Forces, and so on. Figure 5 shows the trajectories of helicopters observed during sea disaster prevention training, which was conducted in the Seto-Naikai Sea in October 2012.

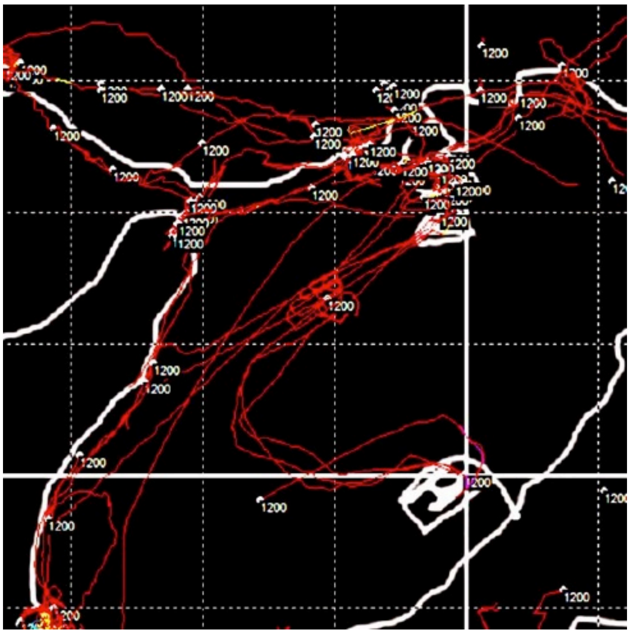

Fig. 5 Observed Trajectories of Helicopters

In Figure 3 and 4, the distance between the range marks is 10km, and that between grids in Figure 5 is also 10km.

It should be noted that the blind-area in the coverage of the master SSR will be the blind-area in the PSSR, and the area near by the straight line connecting the master SSR and the PSSR will be also the blind-area based on the positioning principle described next.

2.2 Positioning Principle of PPSR

Details of the positioning principle of PSSR are described in references, and documentation provided by the Electronic Navigation Research Institute (ENRI). Please refer to the documentation for more information.

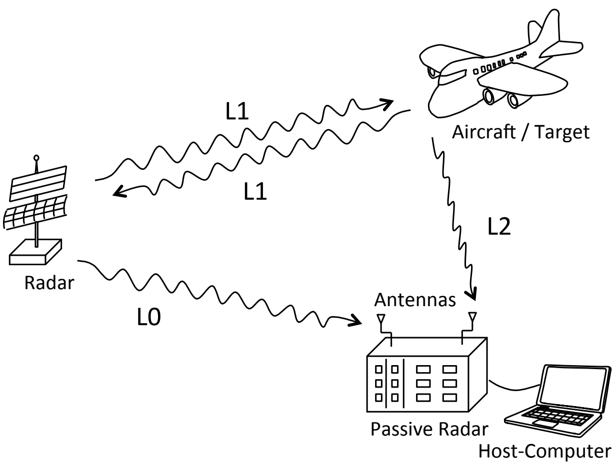

Fig. 6 PSSR Configuration

Operational requirements of the simplest PSSR are as shown in Figure 6. The PSSR must be installed at the place where it can receive SSR Mode-A/C interrogation signals of 1,030 MHz transmitted from the master SSR. Though the PSSR does not have to be installed where the master SSR can be seen, it is necessary to receive SSR interrogation signals reflected by a building or the like. If the PSSR cannot receive any SSR interrogation signals, it would become necessary to add some optional functions to the PSSR for surveillance operation, and the PSSR system would become difficult to use.

In the PSSR of the ENRI model, it is essential to estimate the operational profile of the master SSR by the PSSR. In Japan, the SSR system that is used to monitor the terminal airspace and airway has a scanning period of about 4 seconds and about 10 seconds, respectively, and the width of the scanning beam is about 3 degrees. At the installation location of the PSSR, it receives the interrogation signal sequence (it consists of about 20 times of transmission of interrogation signal) in every scanning by the master SSR, and the precise scanning period can be calculated. By analyzing the content of the interrogation signal sequence, time intervals of every SSR interrogation can be calculated, and interrogation repetition patterns of Mode-A/C can also identified. Finally, the PSSR then can create the operational profile of the master SSR, when it can determine the time when the scanning antenna of the master SSR faces directly to the PSSR.

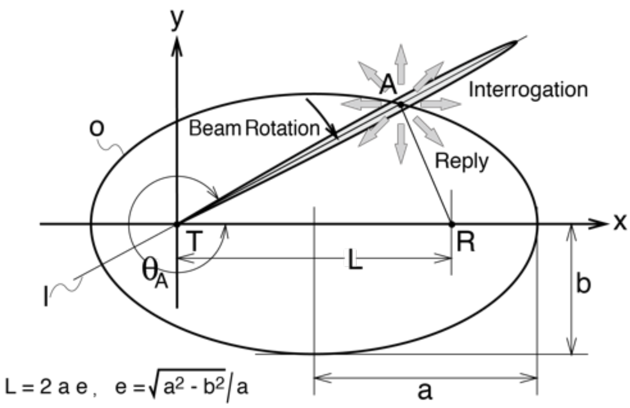

Fig. 7 2D Positioning Principle of PSSR

Figure 7 shows the two-dimensional approximating positioning principle of the PSSR. The PSSR can calculate the interrogation time, direction and mode (Mode-A or Mode-C) from the operational profile of the master SSR. And it can calculate the position of aircraft that transmitted the reply, from position T of the master SSR, position R where the PSSR is installed, the time when the reply signal from the aircraft is received at the PSSR, and the speed of light. The sum of the interrogation signal propagation time from the master SSR to the target aircraft, and the reply signal propagation time from the aircraft to the PSSR give the positioning ellipse which has two focuses of positions T and R. Position of the aircraft is calculated as the intersection of the

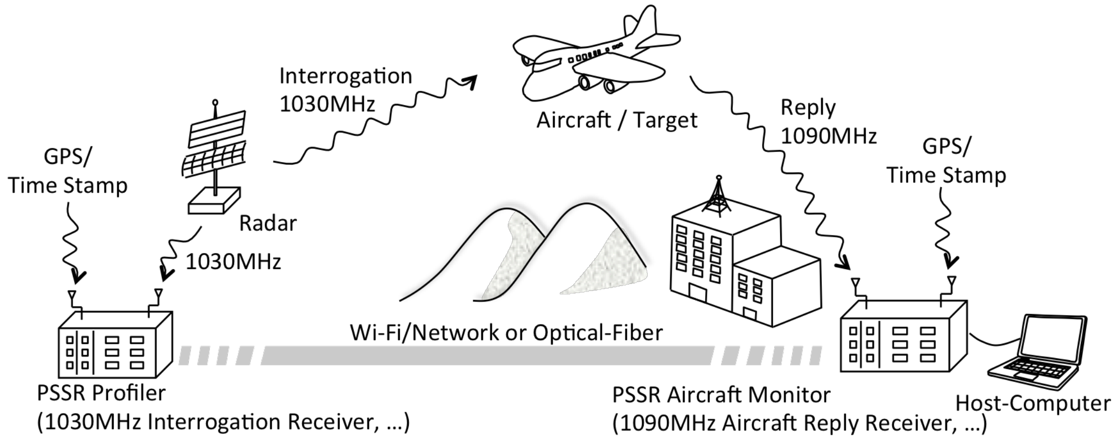

Fig. 8 Network Configuration of PSSR System

positioning ellipse, and the direction line of the scanning antenna of the master SSR.

Note that the PSSR (#PRIRT1-PF-001A PSSR) calculates three-dimensional aircraft position considering the Mode-C flight altitude information from the aircraft, as shown in Figures 3 and 4. It is confirmed that the aircraft position calculated by the PSSR is well matched to the position given by the ADS-B system. The aircraft position determined by GPS matches the center of the positioning elliptic arc given by the PSSR.

2.3 Current Situation of PSSR Development

The PSSR #PRIRT1-PF-001A has been developed as a result of present-day improved high performance of the PLD (Programmable Logic Device). It was impossible for us to develop the PSSR ten years ago. At least, we think that we had to invest a lot of development costs by more than one order of magnitude to complete the development of PSSR, if we would try to develop the PSSR ten years ago.

Today, in Japan, the PSSR of the ENRI Model corresponds to the demand for a niche field as a device utilized for the purposes of airport environment evaluation, and so on. As the result of developing the PSSR that can monitor all aircraft equipped with a Mode-A/C transponder, it is more reliable than ADS-B that cannot monitor aircraft without ADS-B capability. In 2014, we can feel that the demand for PSSR is increasing.

In recent years, many conventional SSR Mode-A/C systems were replaced with new SSR Mode-S systems. As a result of updating the SSR, in some case of PSSR installation, the PSSR ceased functioning. In the case of PSSR installation within the coverage of a new SSR Mode-S as the master SSR, the PSSR cannot calculate the position of target aircraft according to the positioning principle mentioned above, since it cannot create correct operational profile of the master SSR.

Even if the PSSR is installed at the place where it can receive SSR Mode-S interrogation signals, it cannot create the operational profile of the master SSR from monitoring its interrogation signals of a beam width of about 3 degrees, when the scanning antenna of the master SSR faces the PSSR. In the SSR Mode-S surveillance operation, the transmission time interval of each interrogation was controlled by using applying techniques such as staggered in time, since the scanning speed of the SSR is critically controlled.

Full operational profile of the master SSR is essential to the operation of PSSR. To resolve the problem due to the staggered interrogation transmission time, it is necessary to install new equipment for profiling the master SSR. We decided to install the PSSR Profiler close to the master SSR for monitoring the interrogation signal during the entire time of the scan. As shown in Figure 8, the PSSR can be separated into the PSSR-Profiler and the PSSR-Aircraft-Monitor (PSSR-AM). And the network oriented PSSR (PSSR-NW) was developed by synchronizing the PSSR-Profiler and the PSSR-AM by using the GPS clock.

When the PSSR-Profiler and the PSSR-AM were connected via Internet and Wi-Fi, the PSSR-NW could provide the airspace surveillance information as shown in Figure 9. In this example, the PSSR-AM was installed in Kani city at a distance of approximately 17km from the SSR (as the master SSR) installed at Komaki Airport (Prefectural Nagoya Airport) for terminal airspace surveillance, and the PSSR-Profiler was also installed in Kashiwamori at a distance of approximately 10km from the master SSR.

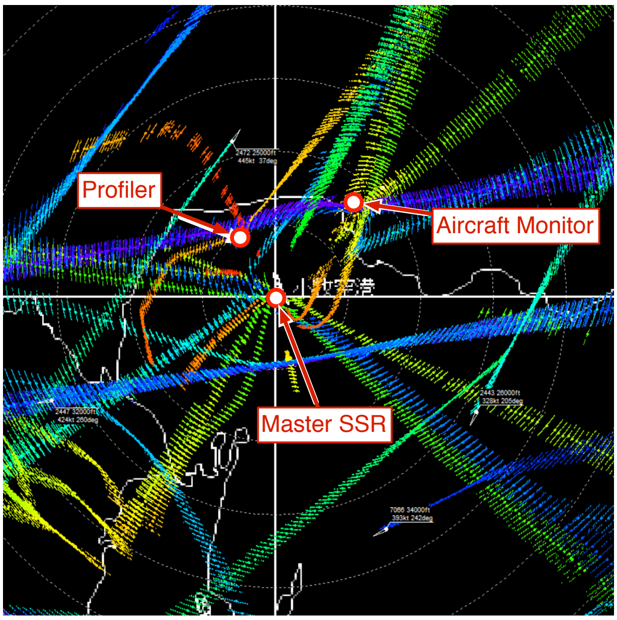

Fig. 9 Observed Trajectories of Aircraft

Figure 9 shows trajectories of the aircraft that have passed through the airspace over Komaki airport. In Figure 9, it is also possible to recognize the blind area mentioned in Section 2.1 above. The elliptical area whose long axis is a straight line connecting the position of the master SSR and the installation position of the PSSR-AM are a blind area.

Blind area is associated with the PSSR due to the positioning principle, and it is dependent on the installation position of the PSSR-AM. It is not possible to solve the problem on the blind area in principle of the PSSR of the ENRI Model. It is impossible to eliminate the blind area by single installation of the PSSR.

3 Passive Primary Surveillance Radar

Originally, radar was the system that receives the reflected radio waves from the target that irradiated radio waves from the radar to measure the distance to the target object. It is necessary to narrow scanning beam width in order to improve the accuracy of angular measurement, and a huge antenna is necessary to enlarge the monitoring coverage by improving the receiver sensitivity, since the radio wave reflected from a target at a long distance is very weak.

For the airspace monitoring purposes of today, there is the primary surveillance radar (PSR), which is operated as a component of airport surveillance radar (ASR). In terminal airspace, there are some situations when aircraft transponders do not respond to the SSR interrogation signal depending on the attitude of the aircraft. The PSR is necessary to monitor the aircraft whose transponder is not working due to such circumstances.

The PPSR (Passive Primary Surveillance Radar) has been derived from the PSSR, and it is developed from the need to compensate for the lack of airspace monitoring by the PSSR, such as described above. The positioning principle of the PPSR is the same as the PSSR shown in Figure 7 and Figure 8, and the PPSR operating requirements for wider deployment is also the same as the PSSR shown in Figure 9.

IRT Corp. has been developing the PPSR that assumes the ASR as the master PSR/SSR. When the master station is a PSR, which is a component of the ASR, the PPSR handles reflection signals of the scanning probe signals of 2.8GHz transmitted by the PSR. When the master station is a SSR, the PPSR handles reflection signals of the Mode-A/C/S interrogation signals of 1,030MHz transmitted by the SSR.

3.1 PPSR 1,030MHz

Figure 10 shows radar echoes obtained by processing a reflection of the interrogation signal of 1,030MHz by the prototype PPSR system in 2011. Figure 11 shows the results of observation by the PSSR at the same time.

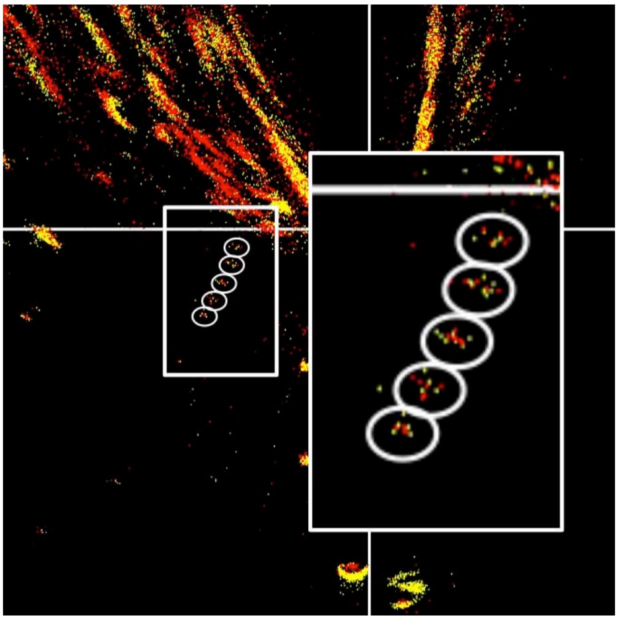

Fig. 10 Radar Echoes Observed by PPSR

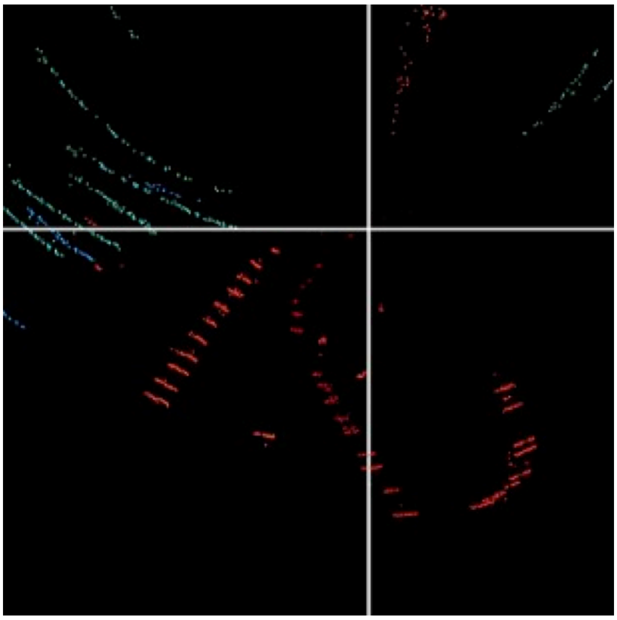

Fig. 11 Trajectories Observed by PSSR

Though transmission power of the SSR interrogation signal is about 1kW, and weaker than the PSR (~ 30kW), it is possible to observe radar echoes of aircraft cruising near the airport by using the horn antenna with high gain, and it is confirmed that the PPSR has the capability to provide aircraft trajectory as shown in Figure 10.

3.2 PPSR 2.8GHz

When the PSR installed at the airport is set as the master PSR of the PPSR, it would be possible to observe wider airspace, since the power of scanning radio wave transmitted by the PSR is much stronger than that of the SSR.

Figures 12 and 13 show the results obtained by the PPSR installed near the PSR as the master radar system installed at Komaki Airport. In Figure 12, highways, steel towers of electric power lines, and high-rise buildings are observed as background noise. In Figure 13, a clear U-shape trajectory is observed in the center.

The radar images provided by the PSR/PPSR are not as good for target aircraft

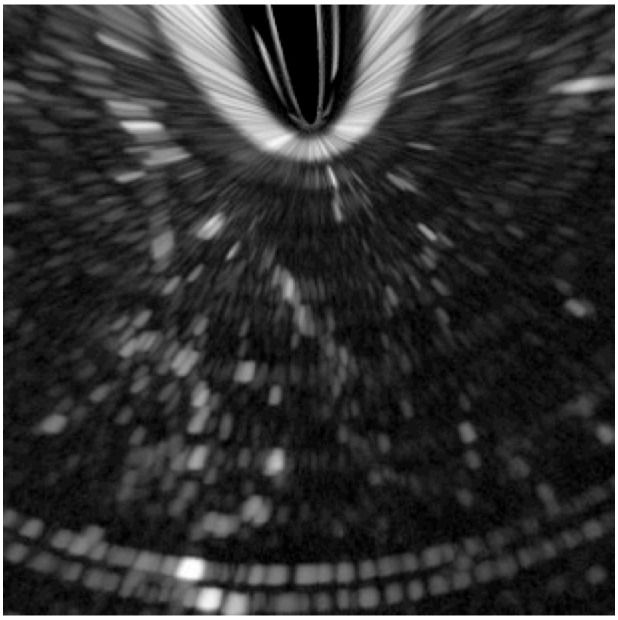

Fig. 12 Background Noise of PPSR

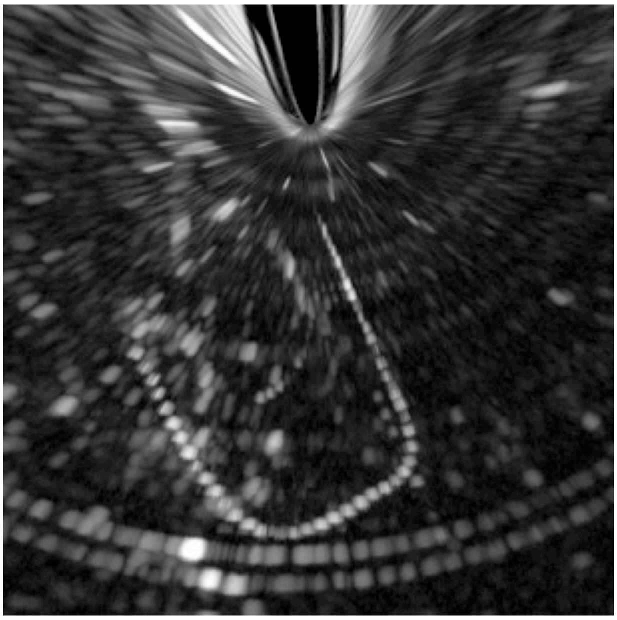

Fig. 13 Trajectory Observed by PPSR

identification as those provided by the PSSR, since there are many kinds of noise in the images provided by the PSR/PPSR. The PSSR provides the processed airspace surveillance image with symbolized aircraft data, but the PPSR cannot provide such an image in its current state.

The latest PPSR can provide the state of the cumulonimbus as shown in Figures 14 and 15. Figure 15 shows the radar echoes of clouds observed 200 seconds after from the clouds observation shown in Figure 14.

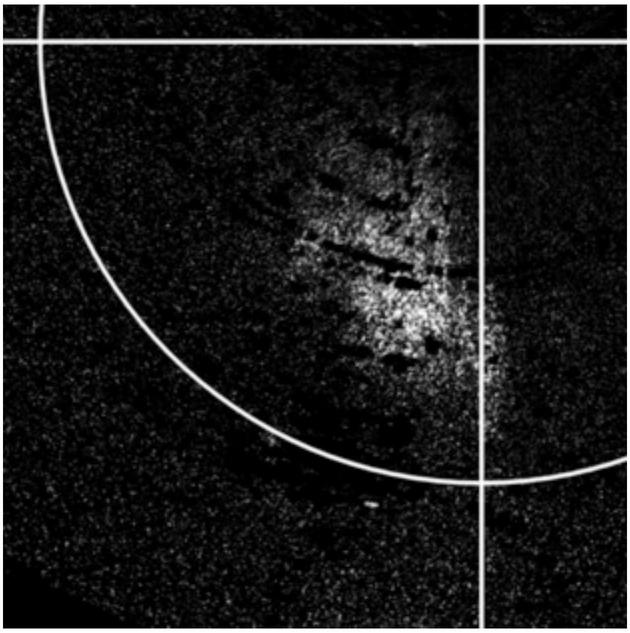

Fig. 14 Clouds Observed by PPSR

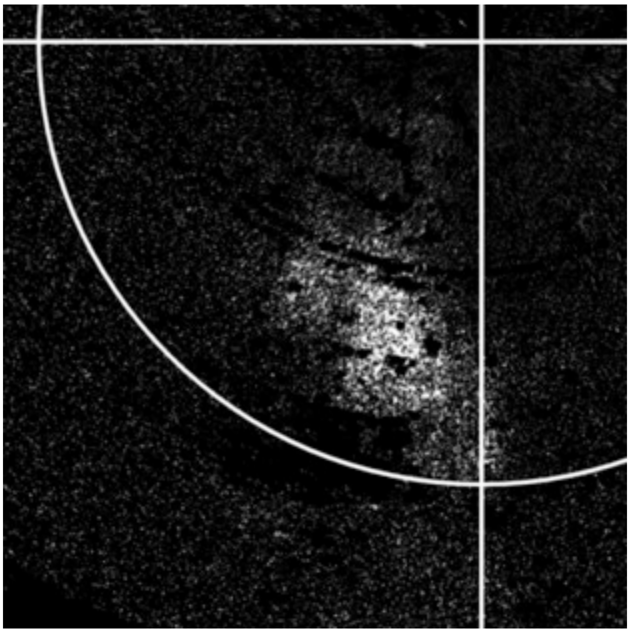

Fig. 15 Clouds Observed by PPSR

4 Conclusion

In this paper, the authors have introduced the passive radar system that was developed according to the positioning principle proposed by ENRI. All the passive radars in this paper are developed by IRT Corp. under the collaboration with ENRI.

We are confident that we can develop very compact and extremely high-performance passive surveillance radar. We think that the #PRIRT1-PF-001A PSSR may be the smallest in the world in 2014.

In the current state, the PPSR and PSSR as our products are stand-alone operation models. The network oriented passive radar system is in a situation that began to develop after its conceptual confirmation.

It is necessary to hear requests from the users to decide the future course of our development.

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