DEVELOPMENT OF MOBILE PASSIVE SECONDARY SURVEILLANCE RADAR

Kakuichi Shiomi*, Atsushi Senoguchi* and Shuji Aoyama**
***Electronic Navigation Research Institute, Japan, **IRT Corporation, Japan**
shiomi@enri.go.jp; senoguchi@enri.go.jp; yhe05237@nifty.com

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Abstract

The Secondary Surveillance Radar (SSR) is used for air traffic control (ATC) monitoring of aircraft in airspace. We then planned to develop an economical Passive SSR (PSSR) system that is capable of providing almost identical information to the current SSR. The PSSR is a system that operates as a slave system of the conventional SSR as a master system, and it provides mode-A and mode-C SSR information without any radio transmissions for transponder interrogation.

In this paper, we present the latest compact and the most cost-effective PSSR system for monitoring aircraft cruising within the coverage areas of any conventional SSR.

1 Introduction – History of R&D

The SSR is currently widely used around the world for air traffic control (ATC) surveillance. Since the beginning of 1980, Mr. Tomoo Ueda had been developing the PSSR that was expected to be a convenient aircraft monitoring system that uses conventional Mode-A/C SSR signals. In 1988, Kakuichi Shiomi, one of the authors, participated in the development of the PSSR. We established the basic concept of the PSSR system as shown in Fig. 1, and we developed the first prototype of the PSSR in 1992, and started the evaluation of the function for obtaining trajectories of aircraft cruising in the airspace by using this PSSR [1, 2, 3].

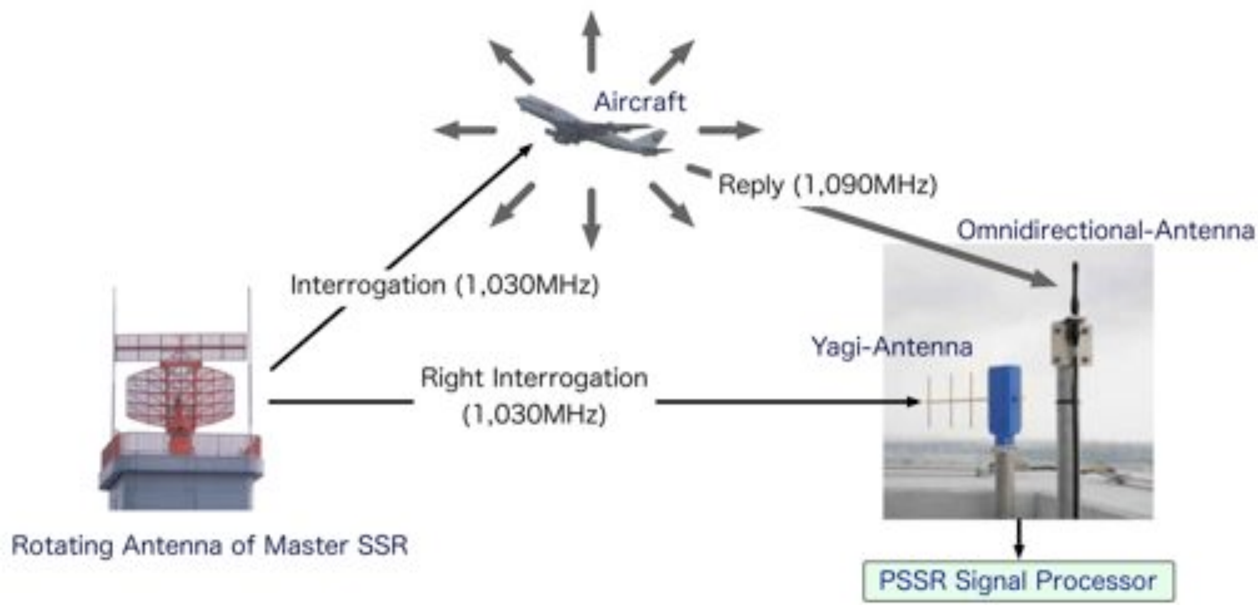

Fig. 1 Standard Operational Setup with Minimum Configuration of ENRI's PSSR

2 Principles of the PSSR

Figure 2 shows the positions of a master SSR interrogating antenna, a target aircraft and a PSSR installation. The master SSR antenna rotates continuously, transmitting interrogation signals from point *T*. When an interrogation signal is received by the transponder on board the aircraft at point *A*, it broadcasts a reply that is received at a PSSR station located within the coverage area of the SSR at point *R*. Through analysis of the interrogation pulses from *T* received at *R*, the PSSR is able to determine the operational profile information, which consists of the interrogation interval and the angular velocity of the rotation of the antenna of the master SSR. The aircraft position *A(x, y, z)* can be calculated using the equations (4), (5), (6) and (7), from equations (1), (2) and (3).

$$1 = \left(\frac{x - \frac{a}{2}}{\frac{b}{2}}\right)^2 + \frac{y^2 + x^2}{\left(\frac{b}{2}\right)^2 - \left(\frac{a}{2}\right)^2} \quad (1)$$

$$y = x \tan\theta_A \quad (2)$$

$$z = h \quad (3)$$

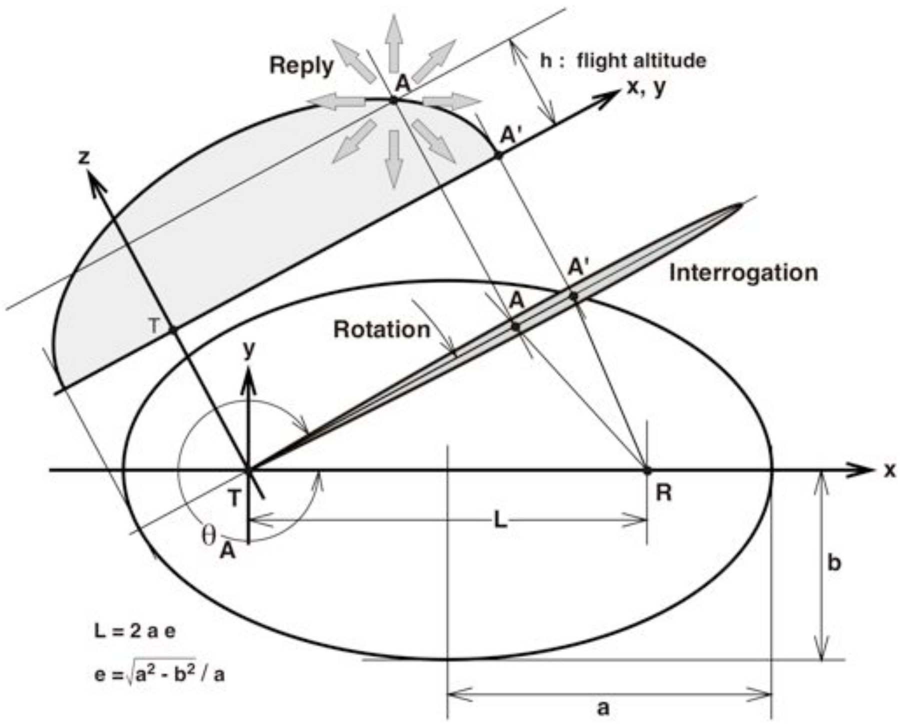

Fig. 2 3 Dimensional Configuration of PSSR for Aircraft Position Measurement

$$x = \frac{a\,(a^2 - b^2) - sign(\cos\theta_A)\, b\sqrt{4\,a^2 h^2 + (a^4 - 2\,a^2 b^2 - 4\,h^2 b^2 + b^4)\sin^2\theta_A}}{2\,(a^2 - b^2 \sin^2\theta_A)} \quad (4)$$

$$y = sign(\sin\theta_A)\,\frac{\sqrt{a^4 - 2\,a^2 b^2 - 4\,h^2 b^2 + b^4}}{2\,b} \quad (5)$$

$$z = h \quad (6)$$

$$sign(x) = 1, when\ x \geq 0;\quad sign(x) = -1, when\ x < 0 \quad (7)$$

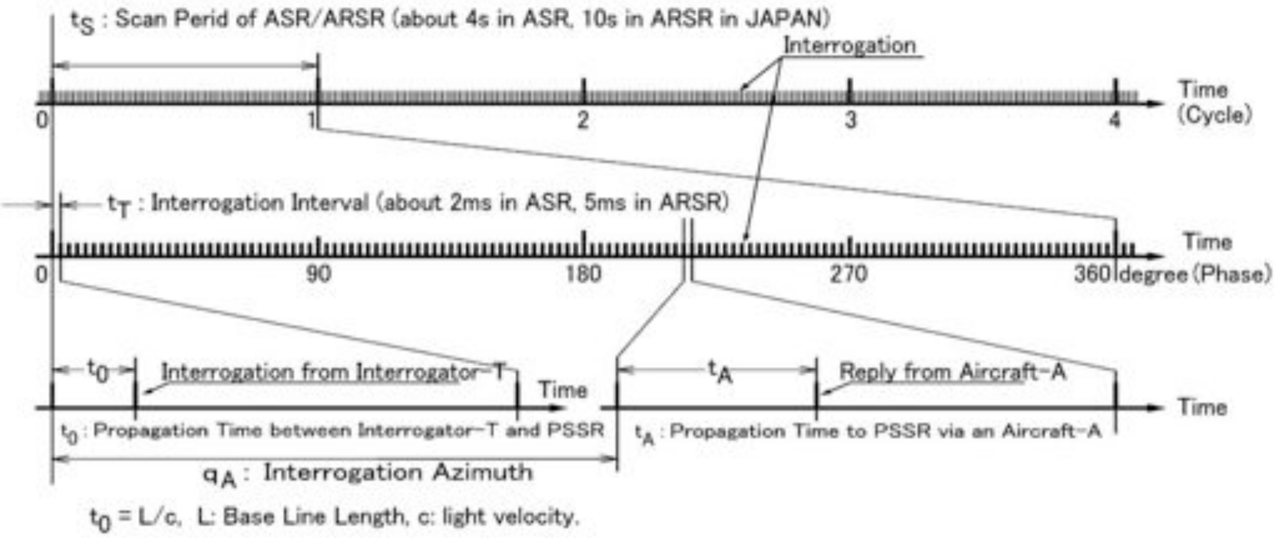

Fig. 3 Timing Chart of PSSR

Figure 3 shows the Timing Chart of the PSSR. Consider an interrogation pulse transmitted from the antenna *T*. The pulse is received at *R* a time t_0 later. Given the distance *L* between *T* and *R*, the time t_0 is then given by

$$t_0 = L/c \qquad (8)$$

where *c* is the speed of light. The same pulse also travels to the aircraft where it triggers a response from the transponder. The response is received at *R* at a time t_A after the interrogation pulse was transmitted (see the Timing Chart in Fig. 3). t_A can be regarded as the time taken for a signal to travel from *T* to *R* via *A*, and the distance *TAR* can be computed as equation (9).

$$TAR = c\, t_A \qquad (9)$$

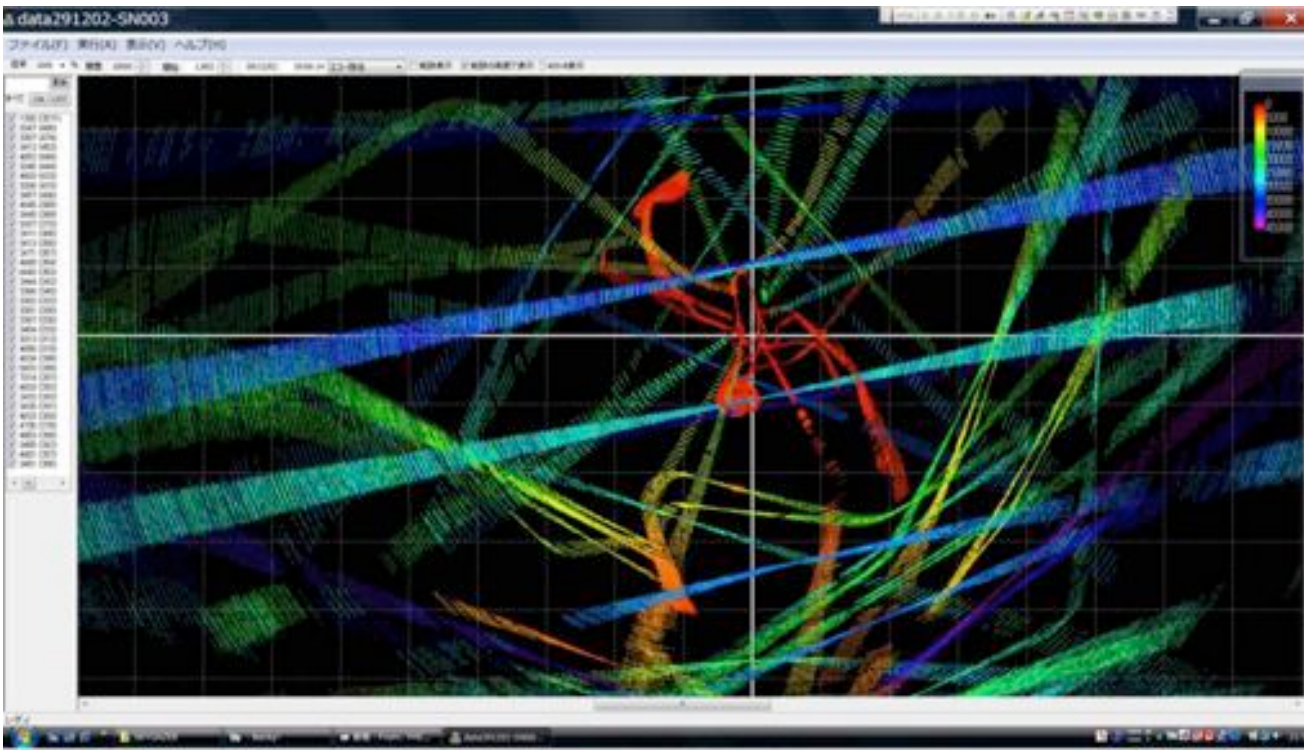

Fig. 4 Aircraft Trajectories obtained by PSSR

The angle θ_A of the antenna of the interrogator which transmits the interrogation to the aircraft A can also be calculated from the angular velocity of the rotation of the interrogation antenna.

3 Experiment Results

Figure 4 shows the aircraft trajectories obtained by the PSSR installed near Komaki Airport in Nagoya, Japan. The coverage of the PSSR system is wider than 100 miles in radius. The warm colored trail is the one of an aircraft that flies at lower altitude, and the complicated movement of a helicopter. Cold colored trail is the one of aircraft that flies at higher altitude. The parallel trajectories of aircraft that fly the air route offset with RNAV are also observed.

Figure 5 shows the aircraft trajectories obtained by the PSSR, and also shows the trajectories plotted with the data obtained by the ADS-B receiver. The trajectory of an aircraft equipped with an ADS-B corresponds to its trajectory obtained by the PSSR. If aircraft positions were assumed to always be the center of the elliptical arc obtained by the PSSR, the difference between the position obtained by the PSSR and that obtained by the ADS-B would be at most a few hundred meters.

It turns out that there are still many aircraft cruising without any ADS-B equipment, in 2012.

4 The Hardware of the PSSR

The PSSR system is an offspring of the low noise radio signal processing technology.

Figure 6 shows the first prototype PSSR hardware developed in 1992. The hardware

Fig. 6 First Prototype PSSR System

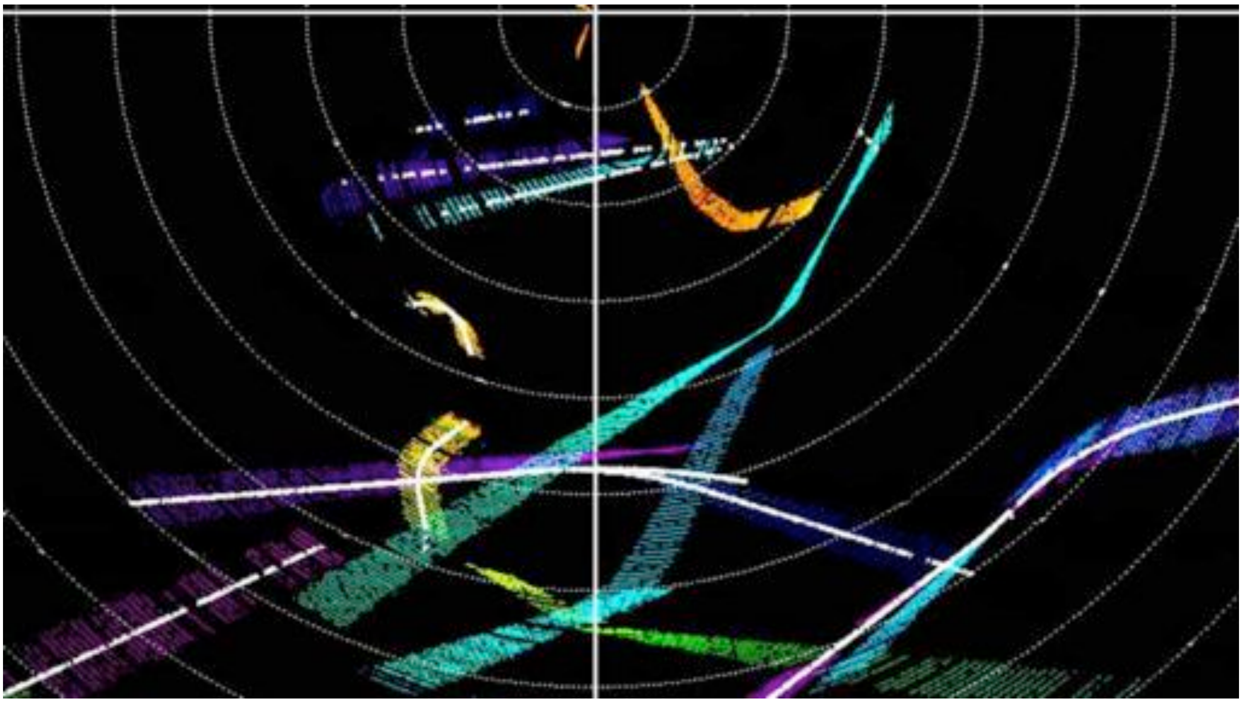

Fig. 5 Aircraft's trajectories obtained by PSSR, and those by ADS-B (white plot)

shown on the left side of Fig. 6 is a signal processor that consisted of NEC-PC and the special RF-hardware that was developed for discriminate SSR interrogation signals and reply signals, and the hardware shown on the right side is the PSSR antennae system that consisted of one omnidirectional antenna and one Yagi antenna.

In 2012, we are now providing two types of very compact PSSR signal processing hardware and antennae as shown in Fig. 7. The mobile PSSR hardware can run on batteries. Both the desktop PSSR and the mobile PSSR are able to provide aircraft position data to a Windows-PC connected by a USB cable, with Mode-A aircraft ID. The very small PSSR hardware is an offspring of the application of software radio technology.

5 Next Step: Network Oriented PSSR

The ENRI's PSSR requires operational profile information of the master SSR for the calculation of the position of cruising aircraft. When the interrogation signal from the master SSR could not be received at the installation

Fig. 7 Latest PSSR Signal Processors (Desktop PSSR S.P. & Mobile PSSR S.P.) and the Antennae (Yagi Antenna & Omnidirectional Antenna)

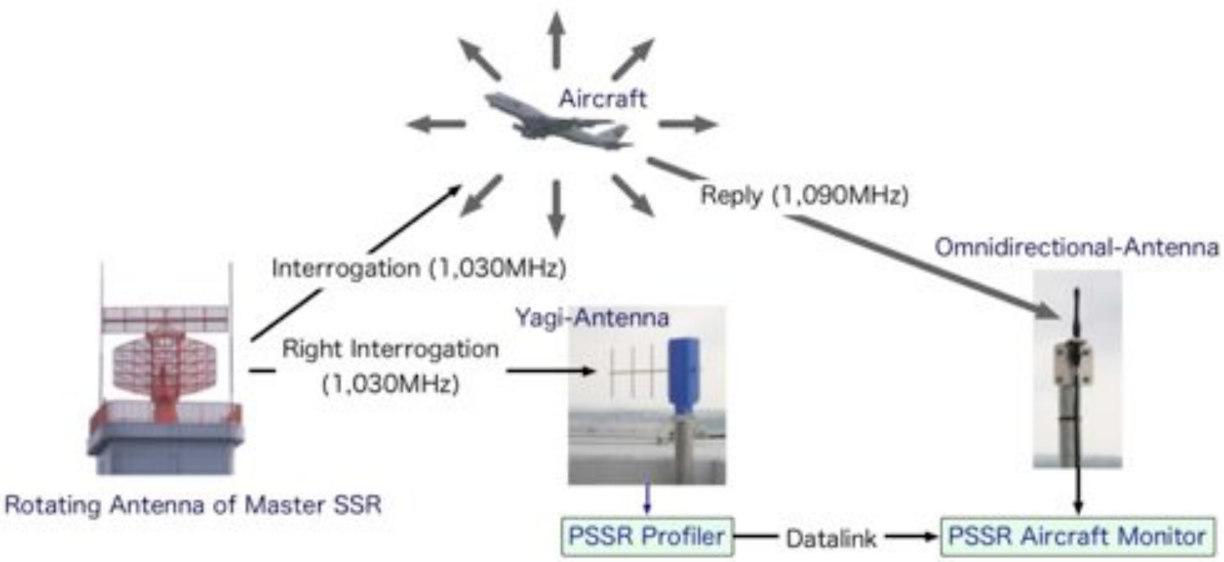

Fig. 8 Configuration of Network Oriented PSSR

location of the PSSR, the PSSR could not make the operational profile information of the master SSR.

Then, we decided to develop the PSSR using a data link as shown in Fig. 8. In this system, the operational profile information of the master SSR is sent to the remote PSSR Aircraft Monitor from the PSSR Profiler installed near the master SSR.

As a result of the experiment, it took about three seconds to send the operational profile information of the master SSR to the remote PSSR Aircraft Monitor installed in the position 30 km away from the PSSR Profiler, when we used the commercial Internet as the data link. As another result of the experiment, it was also confirmed that the remote PSSR Aircraft Monitor provides the same airspace surveillance information as the conventional PSSR.

6 Conclusion

The SSR is used to control aircraft cruising in airways and terminal airspace. About 50 Systems for Air Route and Airport Surveillance are now in operation in Japan. Though installation of SSR mode-S and ADS-B are progressing now, these will not reduce the value of the conventional SSR of mode-A/C that supports operation of commuter aircraft and general aviation.

The PSSR is a convenient system that provides SSR mode-A/C information without any radio transmission such as interrogation signals. The authors can demonstrate the functions of the PSSR system anytime and anywhere within the coverage area of the conventional SSR system.

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