SSR Mode S related researches in ENRI

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Abstract: Secondary Surveillance Radar (SSR) Mode S, an air traffic control radar system, has enhanced surveillance and datalink capability. As the number of Mode S transponder with enhanced capability and SSR mode S ground station increases, new needs and problems are arising. To meet the needs and solve the problems, SSR mode S ground station is needed to add two new functions. To prepare future deployment of new SSR mode S in Japan, Electronic Navigation Research Institute (ENRI) starts to do research and development of new SSR Mode S. In this paper, we mention research and development of two new SSR Mode S functions in ENRI.

Keywords: SSR Mode S, downlink aircraft parameters, interrogator identifier code

1. INTRODUCTION

ENRI has started research and development of two new SSR Mode S functions since 2005 to prepare future deployment of new Mode S Ground Station (GS). The first function is downlink aircraft parameters (DAPs). The second is Interrogator Identifier code (II) coordination.

In this paper, we mention the details of the functions. We first mention the backgrounds of R&D of the functions in section 2. Then, in section 3, we mention the ENRI experimental system which is developed to validate new functions. In section 4, we mention DAPs function. In section 5, we mention II-code coordination function. We conclude this paper in section 6.

2. BACKGROUNDS

In this section, we mention backgrounds of R&D of DAPs function and II code coordination function.

2.1 Downlink Aircraft Parameters (DAPs)

Mode S systems were designed to achieve air-ground digital communication. They have 56 or 80bit data field in interrogation and reply signals. In 1990s, European states launch a project to use Mode S datalink, so called Downlink Aircraft parameters (DAPs)[1][2]. Ground stations obtain aircraft information such as selected altitude, roll-angle, magnetic heading and so on. Those parameters are provided for air traffic controller in order to improve air picture and for systems in order to improve aircraft position prediction in conflict detection algorithms.

Currently, DAPs is mandatory in some European states. Therefore, the percentage of aircraft with DAPs capability in Europe is high (approximately 93 % [3]). In Japan, the number and percentage of aircraft with DAPs is increasing. It is time to start R&D of DAPs

2.2 Interrogator Identifier Code Coordination

A Mode S GS has Interrogator Identifier code (II). II code is set to interrogation and reply signals. By II code, transponders can identify the source of interrogation and GS can distinguish the destination of reply. Mode S II code should be allocated without conflicts between neighbor GS that have overlapped area. If the same II code is assigned to neighbor Mode S GS, GS are not able to achieve continuous aircraft surveillance in overlapped area. (Either of GS is not able to acquire inbound aircraft in overlapped area. what is worth that both GS may not survey aircraft at the boundary of coverage.)

ICAO standards [4] define 4bits space for II code. Fifteen different II codes are available for GS. As the number of SSR mode S station increases, SSR operator is not able to assign II codes without conflicts between neighbor GS.

To keep continuous surveillance in overlapped coverage by the same II code GS, Mode S GS is required to have II code coordination function.

Japan Civil Aviation Bureau (JCAB) has deployed six Mode S GS for airport and eight for enroute since first Mode S GS was deployed in 2003 at Yamada, a neighbor town of Narita city [5]. JCAB is planning to replace SSR at enroute sites and at major airports to Mode S. In the very near future, it is expected that II is not able to be assigned without conflicts between neighbor GS. It is time to develop Mode S GS with II code coordination function.

Fig.1. Exterior view of SSR Mode S Chofu GS

TABLE I. Experimental system

	Chofu GS	Iwanuma GS
Start Operation	April 2008	March 1995
Maximum Coverage radius	250NM	200NM
Transmit power	1.5kW	1.5kW
Rotation Period	10seconds	4seconds

3. EXPERIMENTAL SYSTEM

To validate new Mode S functions by monitoring real aircraft in air, ENRI develops an experimental system. The system is composed of two GS. We show the characteristics of two GS in Table I.

One GS is located in ENRI headquarter in Chofu, Tokyo. The GS was developed in 2008 and is enroute SSR Mode S. It has new Mode S functions. The exterior view of Chofu GS is shown in Fig.1.

Another GS is located in ENRI branch in Iwanuma, Miyagi. The GS was developed in 1995 in the research of SSR Mode S system.

The coverage of two GS at 40,000ft is shown in Fig.2 . Plus markers (+) show the locations of Mode S GS. A black solid line shows the edge of coverage of Chofu GS and the red line shows that of Iwanuma station. The distance between two GS is approximately 160NM. They cover large airspace. East half area of the main land of Japan is covered by the experimental system.

4. Downlink Aircraft Parameters

In this section, we first mention GICB protocol. Then, we mention DAPs motoring using the experimental system.

4.1 Ground Initiated Comm-B protocol

GS use Ground Initiated Comm-B protocol (GICB) to achieve DAPs. This protocol is very simple and designed to quickly downlink 56bits data from transponders. No complicated procedure such as

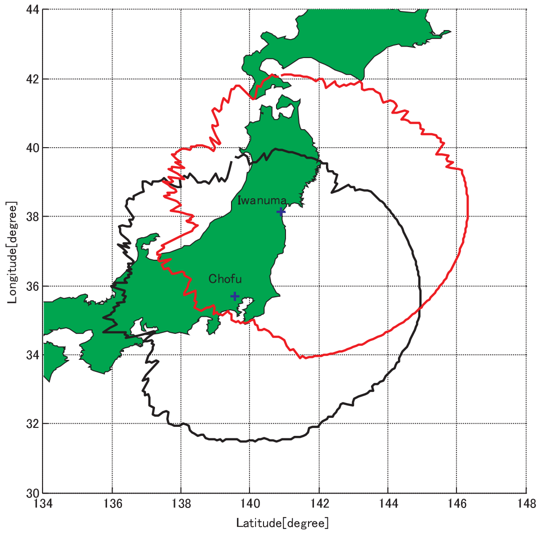

Fig. 2. Coverage of experimental system at 40,000ft

reservations is necessary. GICB is working as following:

1. GS receives GICB request from users or systems
2. GS sets GICB request by designating register address (number) in roll-call interrogation.GS transmits the interrogation.
3. Roll-called Mode S transponder decodes the register address (number) .
4. The transponder fetches a datum at the designated address from a memory space (GICB resister) where 255 types of information data are stored. A datum has 56 bits length.
5. The transponder attaches the datum to reply signal and transmits reply to GS.
6. GS receives the reply with the requested information.

The register contents are shown in Table II. We pick up thirteen out of 255 parameters in the table.

4.2 DAPs monitoring

We develop Mode S GS with GICB function and DAPs controller. Mode S GS obey DAPs controller's request. DAPs controller is COT computer. It keeps aircraft track information and sends GICB request based on aircraft track information such as positions and capabilities.

By using these systems, we conduct DAPs monitoring. In this monitoring, we are aiming at gathering fundamental information needed in developments of applications.

We show the monitoring procedure in DAPs controller in Fig.3. First DAPs controller requests GICB 10, 17 and 20 to aircraft.

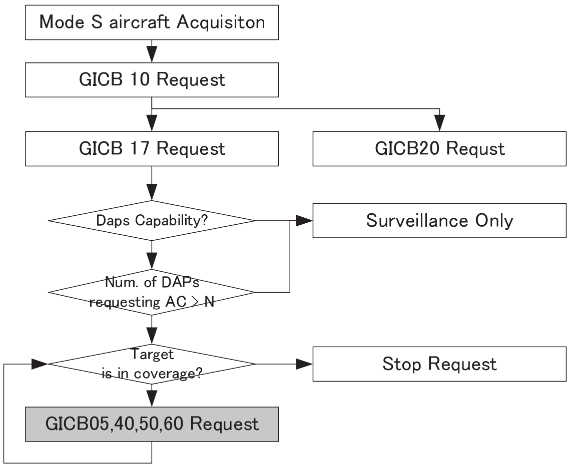

Fig.3. Downlink procedure (N = 6)

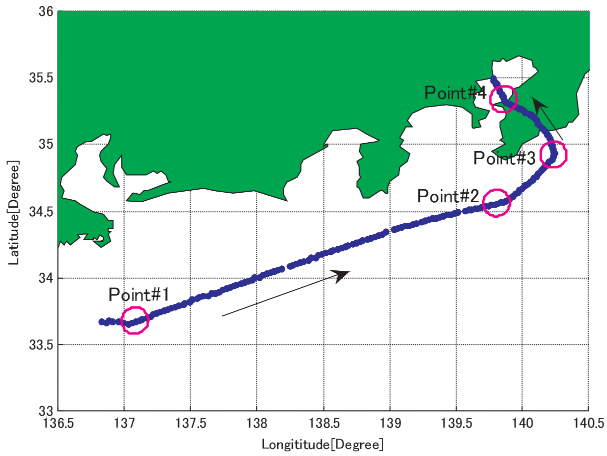

Fig4. Aircraft Track

After GS receives GICB17 reply, it checks the data field. When aircraft has capability to downlink GICB40,50,60,05,DAPs controller requests them in each scan until the aircraft goes out of coverage. So far, to reduce processing load of GS, the number of monitored aircraft is limited to six.

TABLE II. Results of GICB17 monitoring

Register number	Data Content	Num.of aircraft	%
05	Ex-squitter airborne position	569	59.2
06	Ex-squitter surface position	563	58.6
07	Ex-squitter status	602	62.6
08	Ex-squitter identification and type	581	60.5
09	Ex-squitter airborne velocity	592	61.6
0A	Ex-squitter event-driven info.	14	1.5
20	Aircraft identification	591	61.5
21	Aircraft registration number	248	25.8
40	Aircraft vertical intention	584	60.8
44	Meteorological routine report	6	0.6
45	Meteorological hazard report	6	0.6
50	Track and turn report	611	63.6
60	Heading and speed report	588	61.2

4.3 Results of monitoring

4.3.1 Capability monitor

To know how many aircraft with DAPs capability are in airspace in Japan, we monitor the contents of GICB 17. We count the number of Mode S transponders and Mode transponders with DAPs capability.

The results are shown in TABLE II. 961 aircraft with Mode S transponder were observed in autumn in 2008. we find that approximately 60 % of aircraft have GICB20,40,50,60 capability and that some aircraft equip transponder with GICB21,44,45 capability. Additionally, we find that 60 % of aircraft in Japan equip transponder with extended squitter capability(GICB05,06,07,08,09).

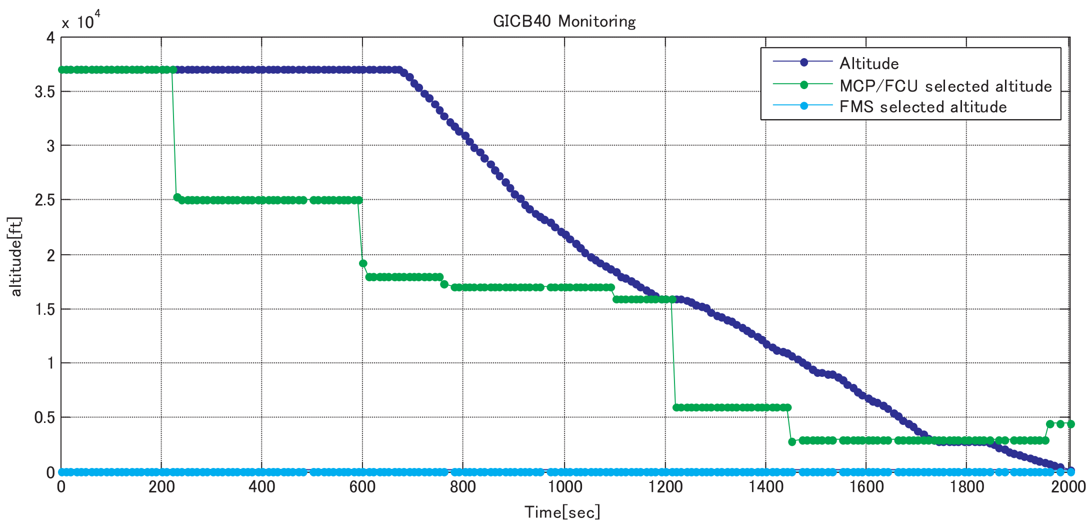

Fig.5. GICB 40 – Aircraft vertical intention

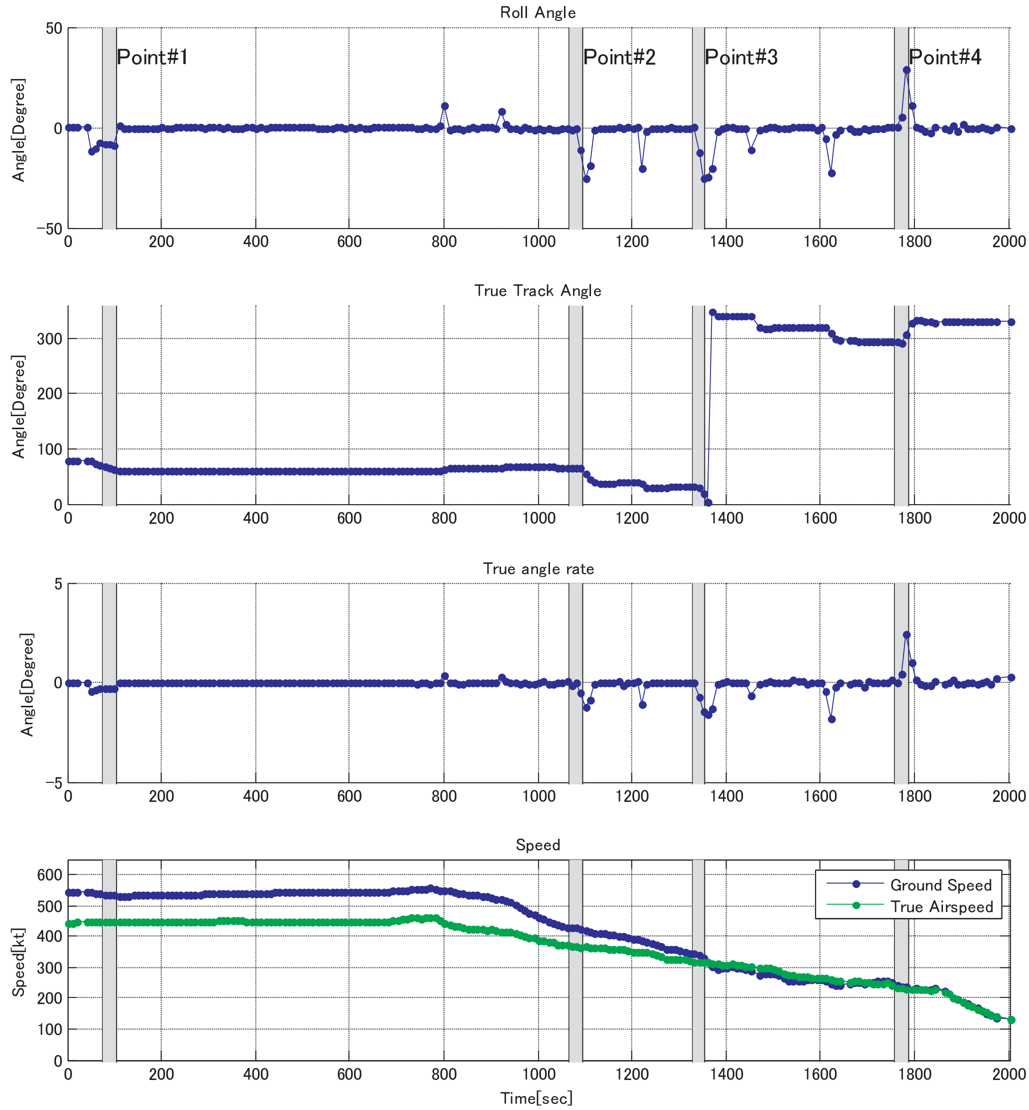

Fig.6. GICB50- Track and turn report

4.3.2 Parameter Monitoring

In this subsection, we show the reuslts of downlink parameters (GICB 40,50) of single aircraft.

The aircraft is initially cruising at FL360, then gradually descending and finally landing Haneda airport. The aircraft horizontal track is shown in Fig.4. We pick up four points where the direction of the track is changing. The monitored aircraft is first heading to approximately 80 degree direction from north. It turns the direction to north and finally heading 330 degree direction.

(1) GICB 40-Aircraft vertical intention

GICB40 contains MCP/FCU altitude, FMS altitude, barometric altitude setting and status bits. Status bits show validity of parameters.

GICB40 parameters of monitored aircraft are shown in Fig.5. X-axis is time in second, Y-axis is altitude in feet. The blue dots are aircraft altitude. The green dots are MCP/FPU selected altitude. The cyan dots are FMS selected altitude.

Pilots set MCP/FCU selected altitude when controller clears the flight level. The MCP/FCU selected altitude is being changed following aircraft altitude. In the final landing phase, pilots seem to set FL45 in the figure 4 to prepare go-around. We find that aircraft is sending reasonable GICB 40 parameters to GS.

(2) GICB50 -Track and turn report

GICB50 contains five parameters, which are roll angle, true track angle, ground speed, track angle rate and true airspeed, and their status bits. GICB50 parameters of monitored aircraft are shown in Fig.6.

Gray bars are points where we judge the track direction changes from the track. Roll angle, True track angle and track angle rate is changing in the points. The transitions of true track angle and speeds are matching to maneuvers of aircraft. We find that aircraft is sending reasonable GICB50 parameters to GS.

5. II CODE COORDINATION

In this section, we mention interrogator identifier code coordination function. Several methods are proposed [2][6] .We decide to develop two methods in two phase. We first develop the Independent Coordination. After the development, we develop the network-aided coordination. In this paper, we only explain the Independent Coordination because the second phase just has started recently.

5.1 The Independent Coordination

In this subsection, we show the details of the Independent Coordination. The coordination is used with combination of two techniques, Stochastic Lockout Override Technique and Lockout Coverage Restriction Technique.

5.1.1 Stochastic Lockout Override Technique

ICAO standards prepare special interrogations to elicit all-call replies from locked-out aircraft, which is called lockout override (SLO) interrogation. When the Reply Request (RR) field in all-call interrogation is set to value 8-12[4], any Mode S transponder have to send back all-call reply with designated probability even if the transponders have been locked out . RR values are shown in Table III.

For example, if transponder receives an all-call interrogation with RR = 9, which means to reply with the probability of 1/2. The transponder virtually throws dice and then sends back all-call reply in case that the value is even.

In SLO technique, Mode S GS interlaces these interrogations into all-call interrogations and transmit them to overlapped area.

5.1.2 Lockout Coverage Restriction Technique

Lockout Coverage Restriction technique (LCR) controls lockout using lockout coverage map. The lock out coverage map is composed of three-dimensional cells. A cell has 5NM × 5NM × 200 ft volumes and contains lockout state. For example, if a state value is 1, aircraft in the cell is locked out by the GS. If the cell value is zero, aircraft is not locked out.

Current SSR Mode S GS in Japan are not using LCR.They lock out all aircraft in their surveillance coverage.

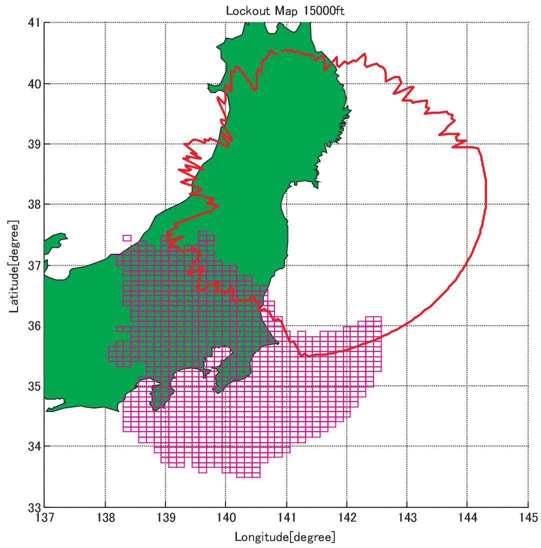

Fig.7. Lockout coverage

TABLE III. Reply Request Field

RR	8	9	10	11	12
Probability	1	1/2	1/4	1/8	1/16

5.2 Experiments for function test

In 2008, we conducted experiments for function test of the Independent Coordination. In this subsection, we first show parameters applied in experiments and then show the results. In experiments, Chofu GS is operated with the Independent Coordination function (SLO +LCR). Iwanuma GS is operated without it.

5.2.1 Parameters

(1) SLO interlace pattern and sector

GS transmits a set of SLO interlace pattern repeatedly in SLO sector. In experiment, we use a SLO interlace pattern that is composed of three interrogations with RR = 1,1/2,1/4 , and 120 degree SLO sector from -45 to 75 degree.

(2) Lockout Coverage Map

Chofu GS use a lockout map to control lockout while Iwanuma GS does not use it and lock out all aircraft in its surveillance coverage. The lockout coverage map at 15,000ft in the experimental system is shown in Fig.7. The pink meshed area is the lockout coverage of Chofu GS. The area sounded by red line is that of Iwanuma GS.

5.3 Results of the experiments

All-call replies are show in Fig.8.Nontheless, transponders are locked out by either Iwanuma GS or Chofu GS, many all-call replies are observed in the SLO sector. On the contrary, the number of all-call replies is reducing at the outside of the SLO sector. We

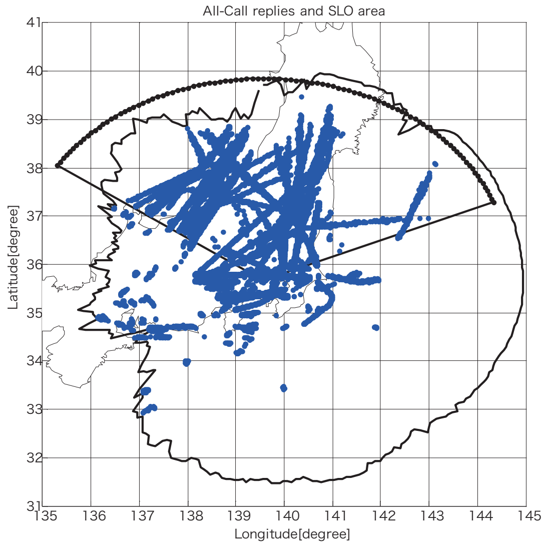

Fig.8. All-call replies and SLO angle

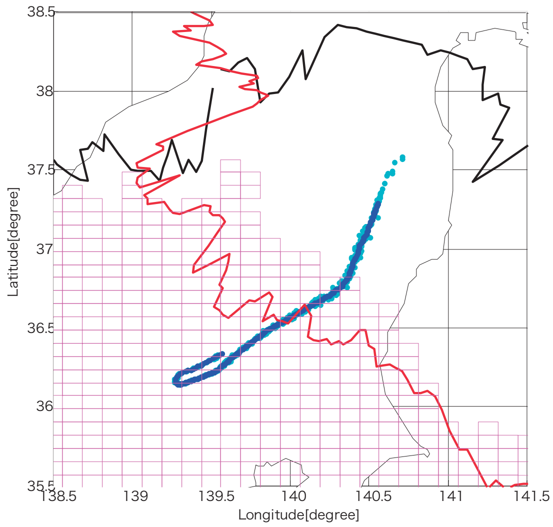

Fig.9. Aircraft Track passing overlapped coverage

find that the SLO function is working correctly in both GS and transponders.

In addition, we analyze tracks of aircraft crossing overlapped area. We show the track of aircraft observed by Chofu GS in Fig.9. The blue dots are roll-call replies and the cyan dots are all-call replies. The red lines is the border of the Iwanuma lockout area and pink meshed area is Chofu lockout area.

By SLO interrogation, Chofu GS acquires inbound aircraft in overlapped area and start roll-call surveillance. The transponder continues all-call replies because of SLO.

We find that Mode S GS are continuously surveying aircraft in overlapped area.

6. CONCLUSION

In this paper, we mention two new SSR Mode S functions.

First we mention DAPs function. We develop Mode S GS with DAPs capability and monitor aircraft in airspace in Japan. We find that approximately 60 % of aircraft in Japan have DAPs capability by monitoring GICB17 and that aircraft are correctly sending reasonable parameters by monitoring GICB40,50.

Second, we mention II-code coordination function. We develop Mode S GS with the Independent Coordination ,which is one of II code coordination technologies. We find that the SLO function is working correctly in both GS and transponders.

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