INTERNATIONAL CIVIL AVIATION ORGANIZATION
Regional Workshop on Aeronautical Surveillance
(Dakar, Senegal, 20 to 21 June 2011)

Agenda item 3: Overview of Primary and Secondary Surveillance Radars

(Presented by the Secretariat)

Summary

This paper presents a brief report on ICAO developments that are of interest to the ASP.
Action by the meeting is **at Paragraph 3.**

Reference

ICAO Annex X Volume IV Surveillance and collision avoiding Systems
ICAO Annex 10, Volume III Part I: Digital Data Communication Systems, Chapter 9
ICAO DOC 9684 Manual on Secondary Surveillance Radar (SSR) System
ICAO Doc 9688 Manual on Mode S Specific Service

This Working Paper is linked to ICAO strategic objectives **A** & **C**

1. Background

At the conclusion of the Second World War the rapid wartime development of radar had obvious application in Air Traffic Control as a means of providing continuous surveillance of the traffic disposition, independently of aircraft position reports made by radio. This increased precision would also permit a reduction in the existing procedural separation standards. This in turn promised considerable increases in the efficiency of the airways system.

2. Discussion

2.1 The aeronautical Primary Surveillance Radar has been derived from the military facilities capability to, by means of **RA**dio wave, **D**etect **A**nd **R**ange (**RADAR**) the position of a target without its cooperation. These targets that were considered as **foes** to be eliminated in military operations became **friends** to be protected through suitable separation of aircrafts by civil aviation ATC provided with PSR target displaying system. A brief history on the development of PSR is presented in **Appendix**

2.2 Primary Surveillance Radar (PSR)

The principle of the PSR is described as below:

a) The radar antenna illuminates the target with a microwave signal generated by a powerful transmitter;

b) The microwave signal is naturally reflected by the target without the target cooperation;

c) The reflected signal is then picked up by the antenna to feed a sensitive receiving device;

d) The electrical signal picked up by the receiving device is processed to extract the position of the target (azimuth and distance to the target).

2.2.1 Advantages of PSR

The main advantage of the PSR is that **no equipment is necessary on the airplane for this radar to work**, and indeed no equipment on the airplane will help this radar in its ability to see an airplane. This is strictly radio waves emitted from the radar antenna and the reflected radiation being picked up by the antenna.

Moreover the **azimuth of the antenna is measured continuously**, so the direction of the reflected radiation is known as well, thereby allowing the display of a radar hit, or "target", in an appropriate place. The **size of the antenna ensures a good accuracy of the azimuth** measured.

2.2.2 Limitations of PSR

As no equipment on the aircraft contributes through this method, the PSR has some limitations:

a) **Altitude cannot be determined by the simplest of primary radar antennas**. The only way altitude can be figured out is to add another antenna that would "sweep" the sky vertically, such as with a "quad radar", those used for precision approach guidance. In this way, a controller can see the vertical axis on one section of the screen as well as the horizontal axis, and both would plot distance. But the average radar antenna used for airport and airway surveillance is incapable of determining an altitude for a given primary radar return.

b) An aircraft cannot be identified by a specific code and cannot transmit any additional flight data such as ground speed.

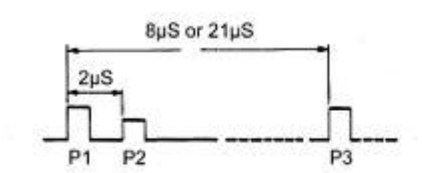
2.3 Secondary Surveillance radar

2.3.1 The need to be able to identify aircraft more easily and reliably led to another wartime radar development, the **I**dentification **F**riend or **F**oe (**IFF**) system, which had been created as a means of positively identifying friendly aircraft from enemy. This system, which became known in civil use as secondary surveillance radar (**SSR**) or in the USA as the air traffic control radar beacon system (**ATCRBS**), relies on equipment aboard the aircraft known as a "**transponder**."

2.3.2 The transponder is a radio receiver and transmitter which receives from earth station Integrator on one frequency (**1030 MHz**) and transmits on another (**1090 MHz**). The target aircraft's transponder replies to signals from an interrogator (usually, but not necessarily, a ground station co-located with a primary radar) by transmitting a coded reply signal containing the requested information.

SSR can provide much more detailed information, for example, the aircraft's altitude, and also permit the exchange of data directly between aircraft for collision avoidance.

a) These data information are provided through several modes of interrogation each indicated by the difference in spacing between two transmitter pulses, known as P1 and P3.
b) Each mode producing a different response from the aircraft.
c) A Third pulse, P2, is for side lobe suppression and is described later. Not included are additional military, or IFF, modes which are described in Identification Friend or Foe.



Mode A and C interrogation format

Mode	**P1-P3 Pulse spacing**	**Purpose**
A	8µS	identity
B	17µS	identity
C	21µS	Altitude
D	25µS	undefined
S	3.5µS	multipurpose

2.3.3 Advantages of SSR

2.3.3.1 SSR improves the ability to detect and identify aircraft;

2.3.3.2 SSR additionally provides automatically the Flight Level of the aircraft and additional flight data (ground speed);
2.33.3 As the target cooperate by replying to the Interrogator the air/ground link budget is more efficient than in the air/ground link budget in the case of PRS.

2.3.4 Limitations of SSR

A number of problems are described in an the ICAO circular 174-AN/110 of 1983 entitled Secondary *Surveillance Radar Mode S Advisory Circular*

Mode A
Although 4096 different identity codes available in a mode A reply may seem enough, but once particular codes have been reserved for emergency and other purposes, the number is significantly reduced in particular with the density of traffic taking into consideration that each aircraft must be assigned an unique A code from departure landing after the flight across many boundaries.

Mode C
The mode C reply provides height increments of 100 feet, which was initially adequate for monitoring aircraft separated by at least 1000 feet. However, as airspace became increasingly congested, it became important to monitor whether aircraft were not moving out of their assigned flight level. A slight change of a few feet could cross a threshold and be indicated as the next increment up and a change of 100 feet. Smaller increments were desirable.

Fruit
Since all aircraft reply on the same frequency of 1090 MHz, a ground station will also receive aircraft replies originating from responses to other ground stations. These unwanted replies are known as FRUIT (False Replies Unsynchronized with Interrogator Transmissions or alternatively False Replies Unsynchronized In Time). Several successive fruit replies could combine and appear to indicate an aircraft which does not exists. As air transport expands and more aircraft occupy the airspace, the amount of fruit generated will also increase.
Garbling

Fruit replies can overlap with wanted replies at a ground receiver, thus causing errors in extracting the included data. A solution is to increase the interrogation rate so as to receive more replies, in the hope that some would be clear of interference. The process is self defeating as increasing the reply rate only increases the interference to other users and vice versa

Synchronous garbling

If two aircraft paths cross within about two miles slant range from the ground interrogator, their replies will overlap and the interference caused will make their detection difficult. Typically the controller will lose the longer range, and later to reply, aircraft just when the former may be most interested in monitoring them closely.

Capture

While an aircraft is replying to one ground interrogation it is unable to respond to another interrogation, reducing detection efficiency. For a Mode A or C interrogation the transponder reply may take up to 120µS before it can reply to a further interrogation.

The ground antenna has a typical horizontal 3 dB beamwidth of 2.5° which limits the accuracy in determining the bearing of the aircraft. Accuracy can be improved by making many interrogations as the antenna beam scans an aircraft and a better estimate can be obtained by noting where the replies started and where stopped and taking the centre of the replies as the direction of the aircraft. This is known as a sliding window process.

Antenna

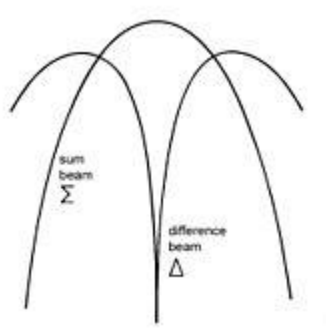
The ground antenna has a typical horizontal **3 dB beamwidth of 2.5°** which limits the accuracy in determining the bearing of the aircraft. Accuracy can be improved by making many interrogations as the antenna beam scans an aircraft and a better estimate can be obtained by noting where the replies started and where stopped and taking the centre of the replies as the direction of the aircraft. This is known as a sliding window process.

The early system used an antenna known as a ***hogtrough***. This has a large horizontal dimension to produce a narrow horizontal beam and a small vertical dimension to provide cover from close to the horizon to nearly overhead. There were two problems:

a) Firstly nearly half the energy is directed into the ground where it is then reflected back up and to interfer with the upward energy causes deep nulls at certain elevation angles and loss of contact with aircraft;
b) Secondly if the surrounding ground is sloping then the reflected energy is partly offset horizontally, distorting the beam shape and the indicated bearing of the aircraft. This was particularly important in a monopulse system with its much improved bearing measurement accuracy.

2.4 Secondary Surveillance Radar Evolution

2.4.1 Monopulse secondary surveillance radar



In order to overcome the deficiencies in modes A and C recognized it was proposed a new interrogation format. The new system was intended to operate with just a single reply from an aircraft, a system known as monopulse.
An antenna diagram comprising a conventional main or "sum" beam of an SSR antenna to which has been added a "difference" beam. To produce the sum beam the signal is distributed horizontally across the antenna aperture. This feed system is divided into two equal halves and the two parts summed again to produce the original sum beam. However the two halves are also subtracted to produce a difference output. A signal arriving exactly normal, or bore sight, to the antenna will produce a maximum output in the sum beam but a zero signal in the difference beam. Away from bore sight the signal in the sum beam will be less but there will be a non-zero signal in the difference beam.
The angle of arrival of the signal can be determined by measuring the ratio of the signals between the sum and difference beams. The ambiguity about bore sight can be resolved as there is a 180° phase change in the difference signal either side of bore sight.
Bearing measurements can be made on a single pulse, hence monopulse, but accuracy can be improved by averaging measurements made on several or all of the pulses received in a reply from an aircraft. Monopulse reply on mode A and C provides improved bearing measurement for the SSR mode A and C system with the advantage that the interrogation rate can be substantially reduced thereby reducing the interference caused to other users of the system.

2.4.2 Monopulse Mode S Secondary Surveillance Radar

In order to prevent FRUIT and synchronous garbling it was proposed to address selectively each aircraft. Due to the limitation of the 4096codes allocated to mode A it was proposed code format of 24 bit allowing 16 million permutations of the aircraft address codes.

Therefore individual states have been allocated blocks 24 bit to be assigned to registered aircrafts codes by (***cf*** ICAO Annex 10, Volume III, Chapter 9).

The Mode S provides accurate data link capabilities between aircraft and ATC opening the way to support ATN application (ADSC, CPDLC...).

However in an space with high density of Monopulse Mode S Radar the transponder can be receive interrogation from various earth stations what calls for a coordination for the assignment of Radar Station Identification code.

3. Action by the meetings

The meeting is invited to:

a) Note the information in this paper;

b) Address in its deliberation issues related to the harmonization of the implementation of Mode S Secondary Surveillance Radars in AFI Region.

Appendix
Historical view on Radar

Neither a single nation nor a single person is able to say, that he (or it) is the inventor of the radar method. One must look at the „Radar" than an accumulation of many developments and improvements earlier, which scientists of several nations parallelly made share. There are nevertheless some milestones with the discovery of important basic knowledge and important inventions:

1865 The Scottish physicist **James Clerk Maxwell** developed his electro-magnetic light theory (Description of the electro-magnetic waves and her propagation)

1886 The German physicist **Heinrich Rudolf Hertz** discovers the electro-magnetic waves and prove the theory of Maxwell with that.

1897 The Italian technician **Guglielmo Marconi** bridged larger distances with electromagnetic waves. As a radiating and receiving aerial element he used a long pole, along which was carried a wire. In Italian a tent pole is known as *l'antenna centrale*, and the pole with a wire alongside it used as an aerial was simply called *l'antenna*. Today Marconi is known as pioneer of radio communication.

1904 The German high frequency engineer **Christian Hülsmeyer** invents the „Telemobiloskop" to the traffic supervision on the water. He measures the running time of electro-magnetic waves to a metal object (ship) and back. A calculation of the distance is thus possible. This is the first practical radar test. Hülsmeyer registers his invention to the patent in Germany and in the United Kingdom.

1921 The invention of the Magnetron as an efficient transmitting tube by the US-american physicist **Albert Wallace Hull**

1922 The American electrical engineers **Albert H. Taylor** and **Leo C. Young** of the Naval Research Laboratory (USA) locate a wooden ship for the first time.

1930 Lawrence A. Hyland (also of the Naval Research Laboratory), locates an aircraft for the first time.

1931 A ship is equipped with radar. As antennae are used parabolic dishes with horn radiators.

1936 The development of the Klystron by the technicians **George F. Metcalf** and **William C. Hahn**, both General Electric. This will be an important component in radar units as an amplifier or an oscillator tube.

1939 Two engineers from the university in Birmingham, **John Randall** and **Henry Boot** built a small but powerful radar using a Cavity-Magnetron. The B- 17 airplanes were fitted with this radar.

1940 Different radar equipments are developed in the USA, Russia, Germany, France and Japan.

Driven by the common war expiry and the general development of the air forces to meaning key players radar technology undergo a strong development push during the 2nd's World War and is used during the „cold war" in large quantities along the German domestic border.