Secondary Surveillance Radar (SSR)

It is a secondary radar system requiring active participation from the aircraft and the ground system.

It allows the basic primary radar information which gives the aircraft position to be supplemented with an identification code and an altitude readout.

Basic SSR operates in Modes A and C.

More modern systems use Mode S.

Mode S SSR is also used by the Traffic Collision Avoidance System (TCAS or ACAS) that allows aircraft to identify potential collisions without assistance from air traffic control.

Principle of Operation

In an SSR system the ground station is the interrogator and the aircraft carries the transponder.

The ground station can ask questions by sending out trios of pulses on 1030 MHz with one of three spacings that will be recognised by the aircraft.

The ground transmission is beamed, usually with a phase array aerial, and therefore sidelobes exist.

The aircraft will respond to the interrogation with a longer train of pulses on 1090 MHz according to the cockpit selections.

The aircraft reply is omnidirectional.

Mode A and C

Interrogation

A reply to a sidelobe would cause confusion about the aircraft's bearing.

Pulse 2 is a standard 2 micro seconds behind pulse 1.

This is used for sidelobe suppression.

The interval between pulses 1 and 3 of the ground interrogation dictates the sort of question that is asked or mode.

The two standard modes and their pulse spacing are as follows:

Mode A - 8 micro seconds - Civil and military identification

Mode B - 17 micro seconds - Civil identification

Mode C - 21 micro seconds - Altitude reporting

Transponder
The aircraft's response on 1090 MHz is a stream of pulses 20.3 micro seconds long framed by two frame pulses.

Between the frame pulses there is space for 12 additional pulses, known as a 12 bit code.

The pulse train is effectively a binary code in which $2^{12}$ or 4096 possible number combinations can be sent.

Aircraft altitude is taken straight from digitisers on the back of the altimeter and is independent of the subscale setting.

It is always referenced to 1013.25mb and is transmitted in the 12 bit code accurate to the nearest 100ft.

i.e. up to +/- 50ft from the actual aircraft height.

Some ground equipment has the capability to adjust this when received to a QNH based altitude for display on the radar screen.

An additional identification pulse can be transmitted 4.35 micro seconds after the pulse train which causes the return on the radar screen to bloom for 25 seconds.

This extra pulse is known as ident or Special Position Identification (SPI).

**Special Codes and Procedures**

7700 - Emergency.

7600 - Failure of two way communications.

7500 - Unlawful interference, hijacking or unlawful interception.

2000 - Aircraft entering an FIR from an area where no code has been assigned or oceanic traffic.

The controller will check that the Mode C readout is within 300ft (200 with some European states) of the assigned level.

If the readout is more than 300ft in error the controller may request that altitude reporting is deselected.

If this fails then you squawk Mode A with the code 0000 to indicate a system malfunction.

**Advantages of SSR**

SSR has a number of advantages over Primary Radar.

1) Since RF energy is only transmitted one way by the ground radar and transponder respectively, both transmitters can be smaller and lighter than those used in Primary Radar.

2) By using a response of coded pulses it is possible to obtain more information from a target than just range and bearing.
3) Secondary radars use different frequencies for transmission and reception therefore they are not susceptible to reflections from very active clouds.

**Mode A/C Errors**

**Fruiting**

If aircraft are in range of two ground interrogators they may reply to both. The received replies may be for the wrong station, this is called fruiting.

**Garbling**

If two aircraft are on the same bearing from the ground station and closer together than 1.7NM they may produce overlapping replies to the ground interrogator. This is garbling.

Both fruiting and garbling are much reduced when mode S transponders are used.

**Mode S**

Whereas Mode A can only handle 4096 identities, Mode S has additional 16 777 214 twenty four bit Aircraft Addresses (AAs) to remove any possibility of ambiguity.

Mode S also stores and is able to transmit on request hundreds of aircraft parameters and it has a comms datalink capability.

Mode S uses the same frequencies as Mode A and C systems and both the interrogators and transponders are backwards compatible.

i.e. A modern ground station can still interrogate a Mode A aircraft and a Mode S aircraft will still give a Mode A and C response to an old-style interrogation.

**Mode S Interrogators**

The architecture of the interrogation element of Mode S is different from earlier systems.

The time interval between pulses 1 and 2 of both systems remains at 2 micro seconds but, whereas the time interval between pulses 1 and 3 of the standard SSR varies and dictates the mode of operation, Mode S transmits a third synchronising pulse 3.5 micro seconds after pulse 1.

This pulse is 1.25 micro seconds wide, changes phase half way through transmission and is immediately followed by 56 or 112 data bits of message.

Mode S interrogators also have a unique code, called either the Interrogator Identifier code or the Surveillance Identifier code. Together called Interrogator Codes (ICs).

The purpose is to identify interrogators which the transponder should either reply to or ignore.

Mode S interrogations can either be to all receiving stations, an all-call or to selected stations.

**Mode S Transponders**
The response from the Mode S transponder is an 8 micro seconds preamble followed by a 56 bit or 112 bit data transmission on 1090 MHz.

The short (56 bit) reply contains only control elements and simple data such as Mode A codes, the pressure altitude or the Aircraft Address.

The longer (112 bit) transmission can contain between 56 and 80 bits of message data from the aircraft avionics systems.

Both interrogation and reply data transmissions have the same structure, though they will have differing contents.

Transponders maintain avionics data in their Binary Data Store (BDS) registers.

There are 256 BDS registers.

Each register contains the 56 bit data payload of a particular long Mode S reply.

Which register is sent depends on the format of the interrogation.

There are 25 standard response formats.

Apart from normal interrogations, some ground stations can command that the transponder include particular BDS data in its reply.

This is called Ground Initiated Comm-B or GICB.

**Mode S Capability**

ICAO classify Mode S transponder capability from Level 1 to Level 5.

Most European states require level 2 capability for aircraft over 5700kg MAUM or with a cruise TAS in excess of 250KT to provide Elementary Surveillance (ELS) functionality.

Some require an Enhance Surveillance (EHS) capability.

**Elementary Surveillance**

This provides:

- A Mode A response.

- Pressure Altitude reporting in 25ft intervals.

- The Aircraft Address. This is pre-set and cannot be changed from the cockpit. It is generated by the Authority of the state in which the aircraft is registered and is nearly always the aircraft registration itself.

- The Flight Status (in flight or on the ground).

- A Data Link Capability Report.
• The Aircraft Identification which is the aircraft callsign (or unusually its registration) set through the FMS.

• A GICB Capability Report, but not GCIB data.

• ACAS Resolution Advisory reporting capability.

There are three different identifiers that can be sent:

1) Mode A code, set through the flight deck.

2) Aircraft Identification (callsign), set through the flight deck.

3) Aircraft Address (a/c registration), which is hard wired in.

**Enhanced Surveillance**

Enhance Surveillance (EHS) equipment must meet the requirements of ELS and must also be able to supply the following data in response to GCIB requests:

• Magnetic Heading

• Selected Altitude

• Indicated Airspeed

• Mach Number

• Vertical Rate

• Roll Angle

• Track Angle Rate

• True Track Angle

• Ground Speed

**Mode S Antennae**

Aircraft over 5700kg MAUM or those with a cruise TAS in excess of 250KT require two Mode S antennae positioned along the centre line on the top and bottom of the fuselage.

The Mode S equipment must be capable of receiving and analysing signals simultaneously on both antennae.

Once analysed the Mode S equipment must be able to choose the most suitable or, if both signals are equally suitable, the strongest signal and select only that receiving antenna for the remainder of the interrogation.

This ability is known as diversity channel selection or antenna diversity.
Mode S Operation

Mode S ground interrogators transmit a Mode S all-call at a steady rate similar to a conventional SSR.

Any Mode S transponder that is not 'locked out' will reply to the interrogation transmitting its 24 bit Aircraft Address (registration) and its Aircraft Identification (call sign).

Mode A and C transponders reply with the appropriate code.

Once a Mode S transponder has been identified and its track established it can be 'locked out' to prevent it replying to any further all-call interrogations from stations with the same Interrogator Code.

It will then still respond to all-calls from new stations with differing Interrogator Codes but only reply to selective interrogations from the 'active' ground stations.

The purpose of this is to reduce the reply rates and thus the possibility of interference.

Selective interrogations use the 24 bit Aircraft Address and are only released when the radar beam is pointing to where the aircraft is expected to be in the sky.

The aircraft reply is the Mode A code, the Aircraft Identification (call sign) and the pressure altitude.

Mode S Broadcast - Squitters

A squitter is a reply format transmission sent without being interrogated.

Mode S transponders send this 'unsolicited information' on 1090 MHz to allow other TCAS/ACAS II equipped aircraft to track their position.

Mode S can also use squitters to send Automatic Dependent Surveillance Broadcast (ADS-B) information such as its position and altitude to ATC and other users.

Squitters are sent randomly from both top and bottom Mode S aerials.