THEORY & PRACTICE

BY THOMAS INMAN

Airborne surveillance history

This story begins with the start of World War II and a movie review. German aircraft posed a terrible threat to England. In response, the British developed a method of using radio waves to detect an aircraft and determine its range. Radio detection and ranging became RADAR. Today, the acronym has become a word of its own. To get the general idea of how a British team overcame obstacles to make radar work, I recommend the film "Castles in the Sky." The movie glosses over some of the technical details, but it does a good job of describing the challenges faced by the scientists.

Radar works by transmitting a powerful burst of energy and starting a timer. The energy will bounce back off an object and be received (detected) by a sensitive receiver. The time between the transmitted energy burst, or pulse, and the received pulse can be used to calculate range.

Once the British had radar working, they had a new problem to overcome. The blips on the screen could not be identified positively as friend or foe. The radar operators could tell an aircraft was present, its range, and whether or not it was getting closer or farther away, but they could not tell if the targets were British aircraft returning home or German airplanes on the attack. For this reason, the engineers developed an active radar system called Identification, Friend or Foe, or IFF. It used the same principles as radar; the target could be detected, and by measuring the time between transmitted and received energy, its range could be determined. The difference is that IFF uses an active transmitter on the aircraft.

> THE EARLIEST SURVEILLANCE SYSTEMS REQUIRED A PLATOON OF TECHNICIANS AND OPERATORS TRAINED TO INTERPRET THE SQUIGGLES ON A CATHODE RAY TUBE DISPLAY. TODAY, ANYONE WITH A SMARTPHONE CAN DOWNLOAD AN APPLICATION TO SEE WHAT AIRCRAFT ARE FLYING AND WHERE THEY ARE GOING.

The IFF system used a technique known as secondary surveillance radar, or SSR. The SSR system would send multiple bursts of energy coded by time. The IFF on board the aircraft would receive the energy bursts, validate them, and then transmit its own coded set of energy bursts, or pulses. With IFF, the Allies could tell which aircraft were their own. Furthermore, they could identify positively which airplane or group of airplanes were being seen.

The original radar antennas were fixed. In addition, they weren't just one antenna, but an array of antennas designed to increase the effectiveness of the transmitted

The original two-digit transponder used A and B pulses, evenly spaced, between the framing pulses F1 and F2. When the system went to four digits, C and D pulses were nestled in between, and an SPI pulse was added beyond F2. The time from the beginning of F1 to the end of the SPI is only 25μS.

power and the ability of the equipment to receive small signals. Over an amazingly short period of time, engineers were able to raise the radar frequencies, resulting in smaller antennas. It wasn't long before the antennas were small enough to mount on a rotating platform. By keeping track of the direction the platform was pointed, radar operators could not only detect a target and determine its range, but also determine its direction.

Both radar and SSR were extremely secret. The secrecy levels were the equivalent to the Manhattan Project in the United States. No one was allowed to refer to the technology by name. The IFF on the aircraft was referred to as a parrot. A whole language of code words developed around the parrot. In general usage, only one survives today, and that is the word squawk. Pilots are told to squawk a number. Squawk has become shorthand for "set your transponder to the following number."

Once declassified, the IFF became known in the civilian world as air traffic control transponders, or just transponders. Originally, the system used two digits to identify the aircraft. Knowing the original system had only two digits is important to understand the rather confusing pulse names used in modern ATC transponders.

The code sent from the aircraft to the ground consisted of two framing pulses, with the information pulses in between, spaced evenly. The A pulses were used to encode a number between 1 and 7. The B pulses were used the same way. For example, for the number 77, all the A and B pulses would be sent. For the number 00, the space would be empty between the framing pulses. Later, the engineers needed to find room for two more digits. They decided to interweave them between the originals. In addition, they added a pulse outside the framing pulses. This pulse is known as the special position identification pulse, or SPI. This is more commonly known as the ident pulse. When the transponder sends this pulse, the air traffic controller will see the aircraft highlighted on his or her screen.

Eventually, these pulses became used in several different ways, or modes. The most commonly known is Mode C, or altitude mode. With the improvement of transmitter and rotating antenna technology, it became easy to determine the range and direction of a target, but not the altitude. Mode C uses the same pulses described above to send altitude information. A special device measures air pressure and converts the pressure reading into an altitude, which is encoded using the same group of pulses. Eventually, a total of five modes came into use

An ATC radar beacon transponder sits on top of a Mode S transponder.

– two of them exclusively for military IFF uses and three for civilian use. Modes A and B are for transmissions of four-digit codes, and Mode C is for altitude. Mode B is not used in the United States.

It helps to think of the SSR and the transponder as a question-and-answer system. The SSR asks the questions, and the transponder gives the answers. Thus, it's important for the system to remain synchronized. For example, when the SSR asks for altitude, the transponder

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needs to answer with altitude information, not the four-digit code.

Over time, more areas of the world were covered with radar, and many radar coverage areas overlapped. As a result, a problem developed of false replies unsynchronized with interrogator transmissions, or FRUIT for short. Air traffic controllers began to contend with intermittent erroneous targets on their radar screens. There were protocols and technology developed to minimize FRUIT, which worked well at first.

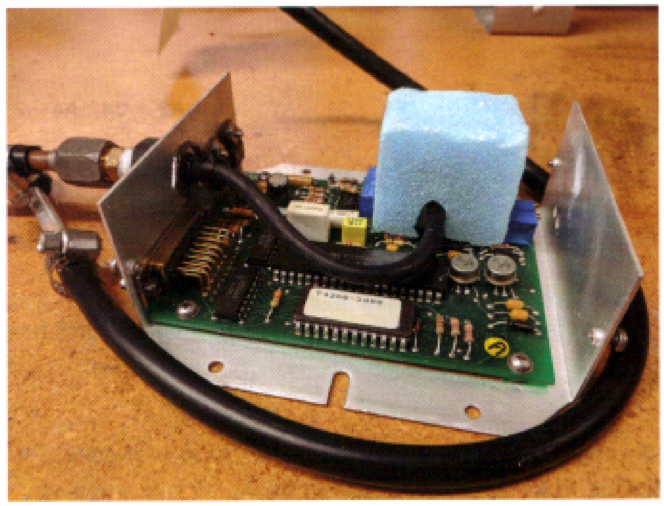
In spite of SSR and transponders, there were collisions between airliners and smaller aircraft. To help solve this problem, engineers developed a collision avoidance system that operated independently of air traffic controllers. It would both alert aircrews to the proximity of other aircraft and recommend evasive action. Known as the Traffic Collision Avoidance System, or TCAS, the system would interrogate transponders on other aircraft. So now, in addition to overlapping SSR areas, there would also be multiple airliners activating transponders.

One feature of TCAS is the ability for two TCAS-equipped aircraft to negotiate a coordinated set of avoidance maneuvers. For TCAS to do this and minimize what would soon be an overload of FRUIT on air traffic controllers' screens, engineers developed a new type of transponder called Mode S, for sequential. For general aviation, these transponders became available in the 1990s.

Mode S transponders have the ability to mimic the original ATC transponder. When Mode S transponders and TCAS systems first were installed in airplanes, the Federal Aviation Administration did not have any active SSR sites that could interrogate Mode S transponders. So Mode S transponders are designed to be backward compatible.

Still, Mode S transponders do much more, and as a result, the pulse system transmitted is completely different. When an aircraft is equipped with a Mode S transponder, it receives a unique identifier code, which positively identifies the aircraft no matter what numbers the pilot sets for a four-digit code. In addition, Mode S transponders will send information about the status of the aircraft, including whether or not it's on the ground, a cruise speed range, and all the information sent by the original ATC transponder. The Mode S transponder sends an electronic beacon called a squitter, which acts like the radio equivalent of a flashing light. Sophisticated Mode S transponders will be connected to TCAS systems and manage negotiation of maneuvers between airliners on a collision course.

An altitude encoder, shown here with the cover removed, measures air pressure and sends the information to the transponder.



Since Mode S transponders have a unique code, they can be called individually. The method of digital information transmitted by a Mode S transponder lends itself to error detection. The combination of better data, error detection, and the ability to call transponders individually allowed the air traffic control system to interrogate transponders less often, which helps to reduce FRUIT.

In spite of all the advantages of Mode S transponders, along with TCAS and improvement in air traffic control SSR with their computer systems, advancements in technology showed us a path to a better way – automatic dependent surveillance-broadcast.

ADS-B has been covered in this publication extensively, and it is the current state-of-the art in airborne surveillance systems. Since it's coupled to a WAAS-enabled GPS, ADS-B will report an exact position in its squitter. Instead of a speed range as reported by Mode S transponders, ADS-B reports exact speed. Not only does ADS-B report the flight status, four-digit code, altitude, and unique identifier just like Mode S transponders, but it also sends a code reporting on the accuracy of the information being sent. With the faster update times and information reporting, the current system is safer and more robust than surveillance systems of the past.

The earliest surveillance systems required a platoon of technicians and operators trained to interpret the squiggles on a cathode ray tube display. Today, anyone with a smartphone can download an application to see what aircraft are flying and where they are going. Air traffic controllers have even better information. With ADS-B In, pilots have information on nearby aircraft, airports and weather. Airborne surveillance has come a long way in a short period of time. ❑